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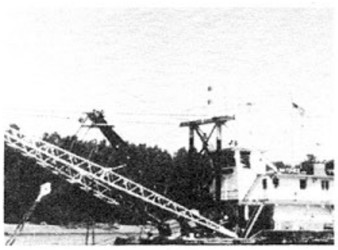

DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

TECHNICAL REPORT D-83-3

EVALUATION OF THE 1980 CAPPING OPERATIONS AT THE EXPERIMENTAL MUD DUMP SITE, NEW YORK BIGHT APEX

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Conflicting, multiple uses of the New York Bight impose various stresses on its physical and biological resources. Ocean disposal of waste poses a management problem which is regulated by no fewer than four pieces of Federal legislation and several State and Federal regulatory agencies. Dredged material disposal in the New York Bight is regulated by the U. S. Army Corps of Engineers. Current regulations dictate that contaminated dredged material be given special treatment. The special

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20. ABSTRACT (Continued).

treatment discussed in this report is the capping of contaminated dredged material with clean material to isolate and minimize transport of toxicants from the sediment to marine biota.

The objective of the project was to assess the potential for placing a cap at the experimental Mud Dump site, and to determine reductions in environmental impacts related to capping. Contaminated sediments from dredging projects in the Hudson Estuary, Newark Bay, and contiguous waters were capped first with fine sediments from the Bronx River and Westchester Creek, then with sand from the Ambrose Channel. The capping resulted in a layer of sand about 1 m thick lying atop the contaminated sediment. Physical, chemical, and biological studies were carried out to determine if the capping effort yielded an intact cap showing resistance to erosion, and if the effort reduced loss of organic and inorganic toxicants from the contaminated material to the water column.

It was determined that a cap was successfully placed at the experimental dump site. The cap was still intact and in place after 16 months. Cap erosion was minor; predictions of cap life were in excess of 20 years under normal meteorological conditions. Major storm events, however, are capable of eroding the cap and exposing the contaminated material. During the 16 months of study, the contaminated material decreased in volume by about 4%. Part of the decrease was due to compaction and part was due to loss of solids during dumping and deposition.

Chemical analyses showed that contaminant levels in the sand cap were lower than in the contaminated sediments. Bioaccumulation studies showed that less contaminant uptake occurred at the capping site than at uncapped dredged material sites and at sites in New York Harbor.

The available data show that capping can be performed successfully in the New York Bight and that the thickness and stability of the cap can act to reduce losses of contaminants to the water column.

Capping can serve as an alternative method for control of contaminants in dredged material. Capping can also be integrated with routine disposal operations to effectively cover and isolate contaminated dredged material at the designated dredged material disposal site.

SUMMARY

Conflicting, multiple uses of the New York Bight impose various stresses on its physical and biological resources. Ocean disposal of waste poses a management problem which is regulated by no fewer than four pieces of Federal Legislation and several State and Federal regulatory agencies. Dredged material disposal in the New York Bight is regulated by the U. S. Army Corps of Engineers. Current regulations dictate that contaminated dredged material be given special treatment. The special treatment discussed in this report is the capping of contaminated dredged material with clean material to isolate and minimize transport of toxicants from the sediment to marine biota.

Regulations to control ocean dumping of wastes first appeared in the mid-19th century. Since that time marine disposal sites have gradually been moved offshore. Most of the research on the environmental impact of ocean dumping has concentrated on the sewage sludge dump site and the dredged material dump site. The greatest mass of wastes disposal in the New York Bight is dredged material (8.3×10^6 cubic meters per year; 1970-1978). Dredged material has formed a substantial mound in the New York Bight that has been studied since about 1968. The greatest environmental impact from dredged material disposal in the New York Bight has been habitat destruction. Little effect has been noted due to contaminant bioaccumulation.

Dredged material comprises about 80% of the solid wastes disposed of at sea each year in the U. S. Most research on impact has concentrated on the effects of particulate matter on marine biota. In 1968, studies were begun to determine the effects of contaminants in dredged material on organisms and ecosystems. Contaminants in dredged material may, under some circumstances, be directly available to biota or capable of leaching from the sediments. Both Japan and the U. S. have carried out studies to determine whether contaminants may be isolated by placement of a cap of clean sediments between contaminated material and the water column. Capping projects have been carried out in Hiroshima

Bay (Japan) and in Long Island Sound (U. S.). The results show that capping can suppress contaminant release and nutrient leaching from bottom sediments. The decision was made, therefore, to carry out a capping project in the New York Bight using sediments from seven dredging projects in the metropolitan New York area.

The objective of the project was to assess the potential for placing a cap at the experimental Mud Dump site and to determine reductions in environmental impacts related to capping. Contaminated sediment from dredging projects in the Hudson Estuary, Newark Bay, and contiguous waters were capped first with fine sediments from the Bronx River and Westchester Creek, then with sand from the Ambrose Channel. The capping resulted in a layer of sand about 1 m thick lying atop the contaminated sediment. Physical, chemical and biological studies were carried out to determine if the capping effort yielded an intact cap showing resistance to erosion, and if the effort reduced loss of organic and inorganic toxicants from the contaminated material to the water column.

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Chemical analyses showed that contaminant levels in the sand cap were lower than in the contaminated sediments. Bioaccumulation studies showed that less contaminant uptake occurred at the capping site than at uncapped dredged material sites and at sites in New York Harbor.

The available data show that capping can be performed successfully in the New York Bight and that the thickness and stability of the cap can act to reduce losses of contaminants to the water column.

Capping can serve as an alternative method for control of contaminants in dredged material. Capping can also be integrated with routine disposal operations to effectively cover and isolate contaminated dredged material at the designated dredged material disposal site.

PREFACE

This report was prepared by the New York University (NYU) Medical Center, New York City, and Valley Ecosystems, Warwick, New York, for the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Army Engineer District, New York (NYD), under Intra-Army Order NYD82-135 dated August 1982 and through Contract No. DACW39-82-M-2544. The study was jointly sponsored by the WES and NYD. The WES funding was through the Dredging Operations Technical Support (DOTS) Program funded through the Dredging Division of the Water Resources Support Center. This study will provide input to the Long-Term Effects of Dredging Operations (LEDO) Program work unit on Efficiency of Capping in Reducing Cumulative Effects of Dredged Material Discharge. The LEDO and DOTS Programs are assigned to WES under the management of the Environmental Laboratory (EL) Environmental Effects of Dredging Programs (EEDP). Dredging Division Technical Monitor for DOTS was Mr. David Mathis.

The field research and monitoring reports [Sediment Budget Investigations (Tavolaro 1982), Sediment Cap Stability (Freeland et al. 1982), Chemical Signature Study (NYUMC 1982), and Mussel Bioaccumulation Study (Koepp et al. 1982)] that form the basis for this evaluation are contained in this report in microfiche and are listed as Appendices A through D, respectively.

The report was prepared by Dr. Joseph M. O'Connor of the NYU and Ms. Susan G. O'Connor of Valley Ecosystems. The contract was managed by Dr. Robert M. Engler, Chief, Contaminant Mobility and Regulatory Criteria Group (WES), and Mr. James Mansky, Chief, Water Quality Section (NYD). The work was conducted under the general supervision of Mr. Donald L. Robey, Chief, WES Ecosystem Research and Simulation Division, and Dr. J. Harrison, Chief, EL. Mr. Charles C. Calhoun, Jr., was the Manager, EEDP.

Commander and Director of WES during the preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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York University Medical Center, New York City, and Valley Ecosystems, Warwick, N. Y., for the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

* Appendices A-D were prepared on microfiche and are enclosed in an envelope attached to the back cover of this report.

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles (U. S. nautical)	1.852	kilometers
miles (U. S. statute)	1.609347	kilometers
tons (short)	907.1847	kilograms

EVALUATION OF THE 1980 CAPPING OPERATIONS AT THE EXPERIMENTAL MUD DUMP SITE, NEW YORK BIGHT APEX

PART I: INTRODUCTION

1. The New York Bight is a prime example of conflicting, multiple uses for a single water body. Simultaneously, it supports commercial and recreational fisheries, boating, bathing and transportation, while receiving directly or indirectly the domestic and industrial wastes from a population of about 20 million people. Even prior to the environmental activism of the 1960's and 1970's, waste discharges in the metropolitan New York region were in conflict with human use patterns. A newspaper article from 1878 mentioned New York's waters as "having become impregnated by...kerosene refining factories..." and stated that "...the striped bass...have become so permeated...as to be unfit for the table." Such pollution, in conjunction with much flotsam and jetsam, instigated passage of the Rivers and Harbors Acts of 1890 and 1899. Since that time, dump sites for waste materials from New York City and surrounding towns have gradually been moved offshore, away from the city, to their present locations in the Apex of the New York Bight. Progressive relocation of the dredged material dump site is depicted in Figure 1 (Gross, 1976).

2. Ocean disposal of waste materials has received much attention from environmentalists and Federal regulatory agencies. The principal pieces of legislation governing waste disposal in the oceans are the Marine Protection, Research, and Sanctuaries Act (1972; amended most importantly in 1976) and the Federal Water Pollution Control Act of 1972, as amended in 1977. The National Advisory Committee on Oceans and Atmosphere (NACOA) pointed out the complex interactions of these and other acts (NACOA, 1981; Figure 2) while describing the jurisdiction in Congress for their administration. The National Ocean Pollution Planning Act of 1978 was passed to provide a "comprehensive, coordinated and effective Federal program for ocean pollution research, development and monitoring" (National Oceanic and Atmospheric Administration (NOAA), 1981). Whether the act will meet its rather lofty expectations remains to be seen.

3. Specific environmental concern over dredged material disposal

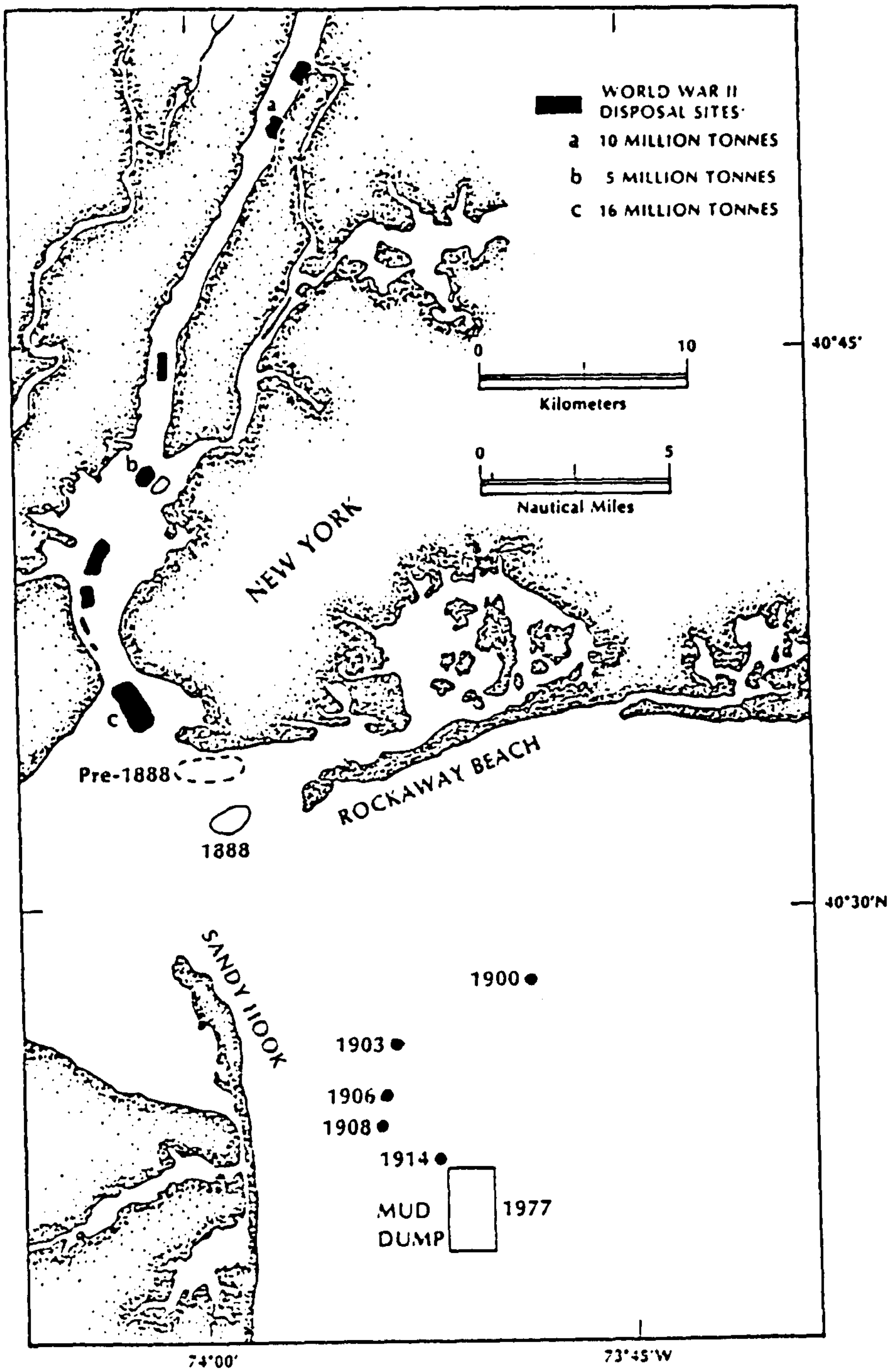
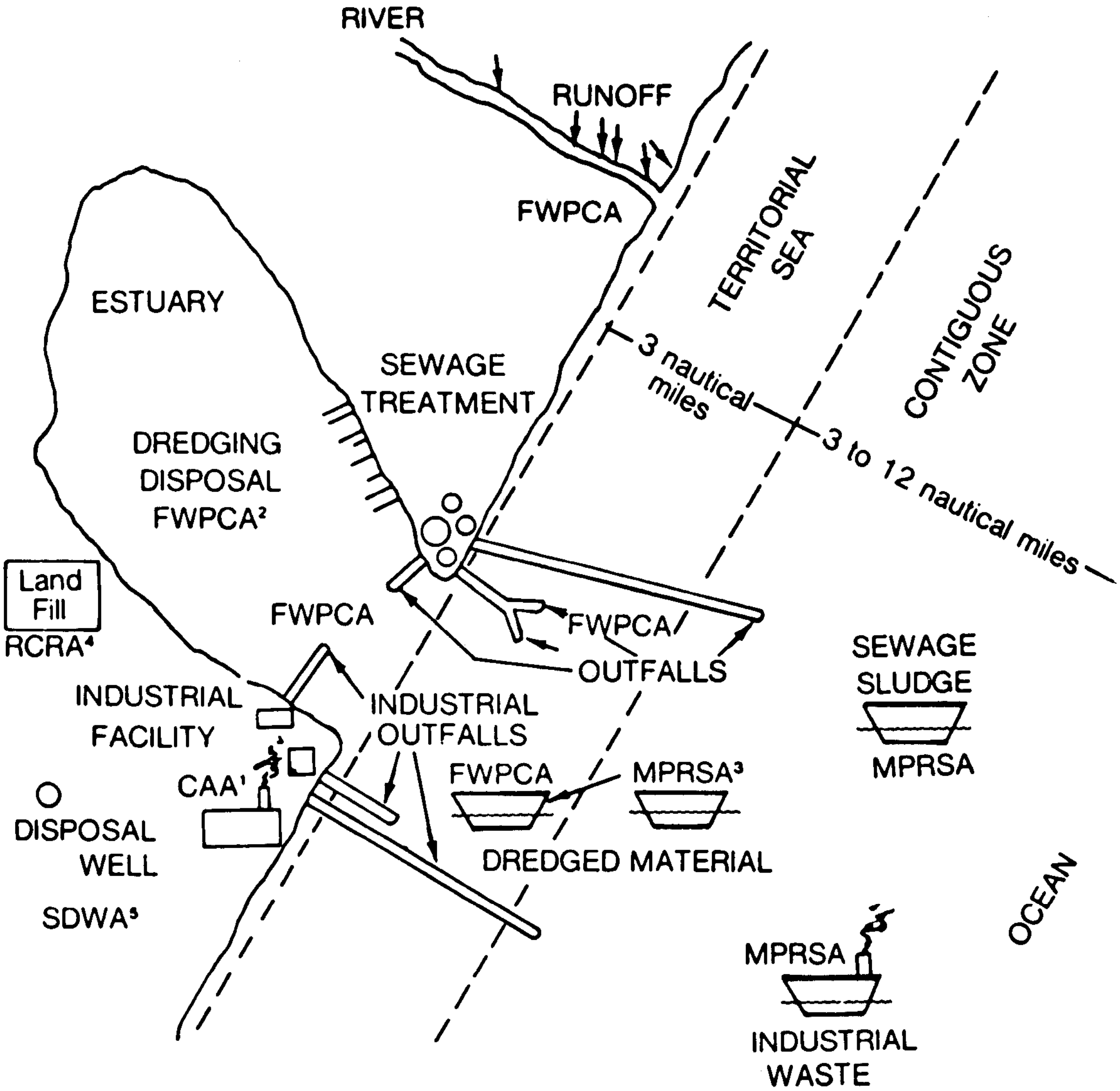


Figure 1. Summary of locations of the dredged material dump site from pre-1888 to the present. Adapted from Gross (1976)



1 Clean Air Act (CAA)
2 Federal Water Pollution Control Act (FWPCA)
3 Marine Protection, Research, and Sanctuaries Act (MPRSA)
4 Resource Conservation and Recovery Act (RCRA)
5 Safe Drinking Water Act (SDWA)

Figure 2. Jurisdictional boundaries of the key environmental laws mentioned in the text (NACOA, 1981)
(A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

has over the years followed its own course, deriving from the Fish and Wildlife Coordination Act (1958), the National Environmental Policy Act (1969), and Title II of MPRSA (1972). These acts combine to give the U.S. Army Corps of Engineers (CE) permit refusal authority, a mandate to study dredged material disposal problems, and the responsibility to establish, in consultation with the Environmental Protection Agency (EPA), criteria for evaluating dredged material prior to disposal into ocean waters (Section 103, MPRSA). Most of these activities are carried out at the CE District level. A manual for evaluating the toxicity of dredged material has been jointly produced by the CE and the EPA (EPA/CE, 1977). Research related to the management of dredged material has, for the most part, been carried out by the CE Waterways Experiment Station under such programs as the Dredged Material Research Program (DMRP) and others (Herner & Co., 1980; Saucier et al., 1980). Such programs have greatly expanded understanding of the chemical, physical, and biological effects of dredged material disposal.

4. Nowhere has the disposal of wastes such as sewage sludge and dredged material received more public and scientific attention than in the New York metropolitan region and New York Bight (NACOA, 1981; Schubel et al., 1979). In 1948, Westman and Bidwell raised the question of whether ocean disposal of wastes was the cause of declines in fish harvest from the New York Bight region. At about the same time, Ayers (1951) and Ketchum and co-workers (Ketchum et al., 1951; Ketchum and Keen, 1955) initiated research in the Bight, and Redfield and Walford (1951) reported for the National Academy of Sciences on disposal of chemical wastes in the ocean. They concluded that the chemical waste disposal practices in effect at that time would not be expected to affect the New York Bight fisheries, but that close monitoring was necessary. Unfortunately, such monitoring was not initiated until 1968 (Gross, 1970; Pearce et al., 1973).

5. Since 1975 large amounts of chemical, biological, and physical data have been produced describing the New York Bight ecosystem and the possible effects of ocean dumping of dredged material, sewage sludge, and various chemical wastes. Appropriate reviews may be found in Gross

(1976), O'Connor and Stanford (1979), and Goldberg (1979) and updated collections of papers and data are now available (Mayer, 1982; Myers, 1982). A comprehensive bibliography of New York Bight publications is available (NOAA, 1974). A severe shortcoming is apparent in the available data; predictions and evaluations of environmental impact due to ocean dumping in the Bight have relied almost exclusively on estimates of contaminant mass loads to the system, and on interpretation by application of laboratory-derived bioconcentration factors (BCF). As more data are obtained, it is becoming clear that the major environmental impacts from ocean dumping are physical effects, i.e., habitat destruction and habitat alteration (NACOA, 1981; Boesch, 1982).

6. The presumption that organisms in nature will accumulate contaminants according to established "principles" of bioconcentration (Branson et al., 1975) appears to be inappropriate when applied to problems of ocean dumping. The appropriate research to determine whether and how contaminants move from ocean-discharged wastes to the biota was suggested as early as 1975 (Fulk et al., 1975; Schubel, 1977), but has only recently been undertaken for the Bight region (Rubinstein et al., in press).

7. While regulatory efforts to control ocean waste disposal intensify (see, e.g., EPA, 1981), it must be recognized that the oceans will continue to play a major role in the waste disposal strategy of the U.S. (NOAA, 1981; NACOA, 1981). Beginning with the DMRP there has developed a strong base of data and experience applicable to the question of how best to manage ocean disposal of at least one major source of wastes - dredged material.

8. The primary objective of this report is to provide an evaluation of a "natural" experiment carried out in the New York Bight Apex beginning in 1980. The experiment (Suszkowzski, 1981) consisted of an attempt to cover and isolate contaminated dredged material with clean capping material and thereby reduce possible environmental impact. Fine sediments from several locations in the Port of New York and New Jersey were precision dumped in the southeast quadrant of the Mud Dump site and

covered with fine-grained material from the Bronx River and Westchester Creek and with sandy material primarily from the main approach channels to New York Harbor. Justification for the project was based upon the success of capping efforts at Long Island Sound disposal sites (see paragraph 43 et seq) and the effectiveness of sand capping in isolating contaminated sediments in a variety of freshwater and marine environments in Japan (Hosokawa and Horie, 1981).

9. The New York Bight, however, is a high-energy environment compared to Long Island Sound or Hiroshima Bay. Therefore, several studies were undertaken to evaluate the capping experiment. These consisted of chemical analysis of dredged material (New York University Medical Center (NYUMC), 1982), an estimate of the sediment budget at the experimental dump site (Tavolaro, 1982), a study of contaminant bioaccumulation at the capping site (N.J. Marine Sciences Consortium (NJMSC), 1982), detailed mapping of the capped site (CE, 1982), and a study of hydrodynamics at the site (Freeland et al., 1982).

10. Together these data showed that: 1) capping can be carried out at an ocean disposal site; and 2) the cap can persist for at least two years. The final efficacy of capping can be evaluated only after detailed chemical studies and further evaluation of the effects of capping on contaminant bioaccumulation. However, capping seems to be effective and should be considered as an alternative management scheme for isolating contaminated sediments from direct contact with ocean waters.

PART II: DISPOSAL ACTIVITIES AND RELATED OCEANOGRAPHIC RESEARCH IN THE NEW YORK BIGHT APEX

11. National legislation was in place as early as 1890 to regulate waste disposal in rivers and harbors. This effectively resulted in the movement of disposal operations to ocean waters. Gradually, several sites evolved as most appropriate for the disposal of a variety of wastes, including acid-iron wastes, sewage sludge, cellar dirt and construction debris, derelict vessels, and dredged material. In the Bight region, these sites centered about the Christiaensen Basin (Figure 1). It is impractical to attempt evaluation of dredged material disposal sites without at least some familiarity with the nature and magnitude of the wastes dumped at neighboring locations.

12. Less than 70 years after Hudson's first visit (1609) to the North River (presently known as the Hudson River), governmental regulations aimed at controlling the disposal of waste materials into New York waters began to appear (Boyle, 1969; Gross, 1974; Gross et al., 1976). Regulations put in place about the middle of the 19th Century to control dumping in New York Harbor waters began the process, still apparent today, of gradually displacing waste disposal sites seaward. Gross (1974, 1976) and Gross et al. (1976) described the history of dredged material dumping in the New York region, including the approximate locations of dump sites from the earliest settlement of New York (1625) through 1977.

13. The other major mass of material disposed of in the New York region consists of sewage sludge from treatment plants in the metropolitan New York - New Jersey area. As with dredged material, "acceptable" (i.e., legislated) locations for the disposal of sewage effluent and sewage sludge have gradually moved seaward from their initial sites in the harbor region.

14. Surprisingly little site-specific research has been carried out at the dredged material and sewage sludge disposal areas in the New York Bight Apex. Prior to the initiation of the MESA-New York Bight

Project, only the National Marine Fisheries Lab (NMFS) at Sandy Hook (see NMFS, 1972) had sampled the water, sediments, and organisms of the Bight region at or near the dump sites. Thus, 20 years or more had passed since the time that Westman and Bidwell (1948) questioned the compatibility of waste dumping and sustained fisheries production in the Bight, and since Redfield and Walford's (1951) recommendation that the status of fisheries and fish habitats in and around the chemical (acid-waste) dump site be monitored.

15. Throughout the evolution of the data base for the different ocean disposal sites in the New York Bight, minimum attention has been given the sites for cellar dirt, construction debris, and acid-iron waste disposal. Discharges of construction debris and acid-iron wastes seem to be of minor import as potential sources of contamination or ecological impact in the Bight (Arnold and Royce, 1950; Redfield and Walford, 1951; Vaccaro et al., 1972; NOAA, 1975; Gross, 1976; Mueller et al., 1976, 1982). In addition, recent economic trends have caused reductions in quantities of construction debris for dumping (Mueller et al., 1982), and the use of the acid waste dump site has been gradually restricted; therefore, estimated annual quantities dumped have declined markedly from 1974 to 1980 (Mueller et al., 1976; EPA, 1982).

16. Most of the data relevant to ocean dumping in the New York Bight, therefore, come from direct or indirect evaluation of the dredged material dump site and the sewage sludge dump site. The dredged material dump site, which has been in use since the turn of the century, was surveyed by the Coast and Geodetic Survey in 1936 (Uchupi, 1970; Freeland et al., 1976; Dayal et al., 1981), and again in 1973, 1978, 1980, and 1981 (Freeland and Merrill, 1977; Dayal et al., 1981; CE, 1982). Dayal et al. (1981) provided a comprehensive record of sediment accretion on the Mud Dump from 1936 to 1978 and a discussion of forces which control the buildup of sediments at the site (Figure 3). A detailed examination of the sediment budget at the experimental Mud Dump site was performed by Tavolaro (1982) and is discussed later in this report.

17. The greatest mass of materials deposited in the Bight Apex is

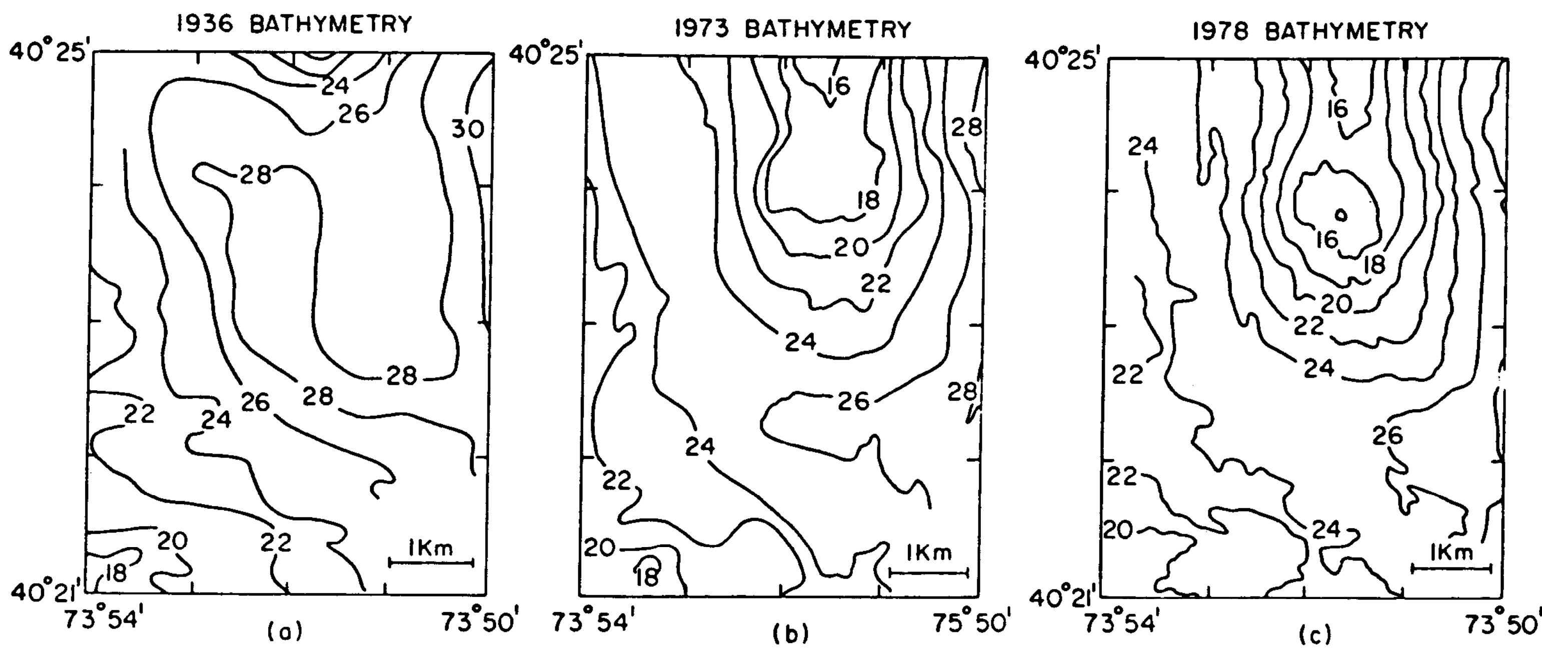


Figure 3. Results of bathymetric surveys conducted at the New York Bight Mud Dump (Dayal et al., 1981). Contours are in meters

dredged material (Gross, 1970, 1974). Most assessments of the Hudson-Raritan Estuary or the New York Bight region provide estimates of annual volume or mass of dredged material dumped in the Bight Apex (NMFS, 1972; Gross, 1970)(Table 1). Assuming the most recent summary of dredged material disposal to be the most accurate, we refer the reader to the most recent EPA environmental impact statement (1982) and to Dayal et al. (1981) for a thorough description of New York Bight dredged material dumping activities.

18. For the period 1970 to 1978, the average annual volume of dredged material dumped in the Bight was 8.3×10^6 cubic meters (10.6×10^6 cubic yards; Conner et al., 1979) of which 64% was from Federal projects and the remainder from non-federal projects. Conner et al. (1979) provided data on both the amounts and particle size distributions of dredged material from major Federal dredging projects between 1966 and 1978. Chemical data (bulk sediment analysis) for disposed dredged material are given by Conner et al. (1979) and NYUMC (1982).

19. The dredged material dump site represents a unique condition in the Bight Apex, that of raised relief on an otherwise flat plain of sandy and gravelly substrate (Freeland et al., 1976; Freeland and Swift, 1978). Changes in relief due to dredged material disposal have most recently been documented by Dayal et al. (1981), Freeland et al. (1982), and Tavolaro (1982).

20. The estimated quantity of material present at the Mud Dump represents some 80 to 95% of the material calculated to have been dumped (Dayal et al., 1981; Tavolaro, 1982). Tavolaro (1982) estimated that most of the losses which occurred derived from the dredging activity itself, and that the "short" estimates of dredged material volume at the Mud Dump result from several factors which affect accurate estimates of sediment volume between dredging site, barge loading, dumping, and settling. These factors (cohesiveness, bulk density, particle size, water content, etc.) and errors in their estimation have been discussed in detail by Gordon and co-workers (Gordon, 1974; Bokuniewicz and Gordon, 1980).

21. Pearce et al. (1981) showed that the mound at the Mud Dump

Table 1. Summary of quantities of dredged material released at the Mud Dump, 1966-1978. Values given are in thousands of cubic yards.

Year	Federal Projects*	Non-Federal Projects†	Section 103 Permits**	Totals
1966	4,165.5	-	-	-
1967	4,514.5	-	-	-
1968	4,931.6	-	-	-
1969	5,778.8	-	-	-
1970	4,053.4	1,663.5	-	5,716.9
1971	10,679.8	6,508.8	-	17,188.6
1972	13,070.0	2,990.4	-	16,060.4
1973	9,243.5	3,454.9	-	12,698.4
1974	6,119.1	3,706.5	-	9,825.6
1975	8,108.7	3,522.8	-	11,631.5
1976	7,617.2	1,673.1	(565.4)**	9,290.3
1977	4,378.8	-	995.5	5,374.3
1978	6,914.0	-	2,246.6	9,160.6
Totals	89,574.9	23,520.0	3,242.1	96,946.6
Averages	6,890.4	3,360.0		10,771.8††

* Conner et al. (1979).

† Conner et al. (1979, Table A-2).

** From CE Annual Report to Congress on administration of ocean dumping activities. 1976 value not included; believed to be low. Conner et al. (1979) estimate substituted in calculations.

†† For 1970-1978 only.

serves to attract marine organisms. Since the mound is made of sediments shown to contain a variety of organic and metallic contaminants (Mueller et al., 1976; Conner et al., 1979; O'Connor et al., 1982), it may serve as a source of contaminants to the biota (O'Connor et al., 1982). An understanding of the interactions between sediment-associated contaminants and the marine biota, therefore, is essential.

22. Chemical studies at the Mud Dump have been confined mostly to the period from 1968 to present. The greatest quantities of data have been accumulated for metals (see, e.g., Greig et al., 1977; Segar and Cantillo, 1976; Wenzloff et al., 1979; Dayal et al., 1981; Simpson and Payne, unpublished; review in O'Connor and Rachlin, 1982). At the present time, however, concern about environmental impact is strongly focused on organic contaminants, especially petroleum hydrocarbons and organochlorines, in ocean-disposed dredged material. While historical data on these compounds at the dumpsite are sparse (NMFS, 1972; Hatcher and Keister, 1976), the more recent literature provides an improved perspective. Survey data from West and Hatcher (1980), Energy Resources Co. (ERCO) (1980), Pequegnat et al. (1980), and MacLeod et al. (1981) (see also Bopp et al., 1981; O'Connor et al., 1982) generally demonstrate that sediments at the Mud Dump contain measurable levels of polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), and persistent chlorinated pesticides.

23. Dredged material disposed at the Mud Dump may affect marine organisms in two ways: first, by exposing them to a range of particle sizes unlikely to exist at non-impacted areas; and, second, by providing a possible source of metallic and organic contaminants to organisms inhabiting the Bight Apex (O'Connor et al., 1982). Impact assessments performed to date have been based upon the assumption that the topographic low spot chosen for dredged material dumping in 1914 was similar, in all respects, to the surrounding seabed. Recent data from vibracore studies (Dayal et al., 1981) suggest this to be a reasonable assumption. Since some of the vibracores taken for the Dayal study penetrated the underlying natural seabed, it is tempting to suggest that the chemical data from such horizons represent conditions on the Apex floor prior to any dumping.

24. Pearce et al. (1973, 1981) demonstrated a reduction in diversity of benthic fauna at the mud disposal site in the Bight Apex. Studies of metals concentrations in shellfish from the middle Atlantic Bight and the New York Bight Apex suggest that metals associated with dredged material disposal and sewage sludge disposal result in higher body burdens in organisms from the Bight region (Greig et al., 1977; Wentzloff et al., 1979).

25. The accumulation of organic contaminants in organisms from the dump site has been assessed in both field and laboratory studies. O'Brien and Gere Engineers, Inc. (1979) and Pequegnat et al. (1980) evaluated bioaccumulation of PCBs and other organics with "natural" experiments. The dredged material dump site was one of several sites tested for accumulation. In each case, bioaccumulation of contaminants was observed at the dump site, but was seen to be less than that occurring within the Lower Bay complex (Gravesend Bay, Brooklyn). Both the O'Brien and Gere (1979) study and the results of Pequegnat et al. (1980) showed that the Mud Dump was no more a source of contaminants to the biota than sediments from other portions of the Bight, or sediments from inside the New York Harbor system.

26. Bioaccumulation information from such studies, however, is perhaps best viewed as input rather than as a conclusion. As pointed out in a variety of reports and publications (Wolfe et al., 1982; Mayer, 1982; O'Connor and Rachlin, 1982), the accumulation of a compound *per se* is neither conclusive nor symptomatic of effects. There exists among both organisms and ecosystems the potential to assimilate measurable levels of contaminants without showing symptoms of toxicity. True cause-effect relationships between contaminants and organisms are difficult to measure in natural environments.

27. Given the vast quantities of contaminants disposed into the New York Bight Apex each year (Mueller et al., 1976, 1982; O'Connor et al., 1982), it is interesting to note the rather low levels to which most marine biota have accumulated toxicants such as Cd, Hg, PCB, and PAH. Much ongoing research is directed toward determining the precise relationships between contamination of sediments, the availability of

contaminants to marine organisms, and the toxicity of the accumulated toxicant.

28. The question of bioavailability has many aspects, including chemistry, physics, and hydrology, all of which may affect the extent to which organisms are functionally exposed to contaminants in sediments. The alternatives available for dredged material disposal must be weighed primarily against the criterion of bioavailability. Using this criterion, couched sometimes in biological terms and sometimes in purely physical terms, decisions must be made regarding where and how to dispose of dredged material most effectively. The remaining chapters of this report provide an overview of various disposal alternatives, including capping, and their relationship to questions of contaminant bioavailability. A detailed discussion of the results of the sand capping operation at the New York Bight Mud Dump is also provided.

PART III: DREDGED MATERIAL MANAGEMENT PRACTICES IN THE COASTAL ZONE

29. Sherk (1971) estimated that dredged material comprised roughly 80% of the solid wastes disposed at sea each year in the U.S. This total, amounting to 22 x 10^6 metric tons (dry), represents a significant problem for coastal cities, such as New York, where sufficient space for upland disposal is not available, and for which disposal in rivers or harbors is an impractical and inefficient solution (Saila et al., 1968; Cronin, 1970; Schubel, 1977; Schubel et al., 1979). The sheer magnitude of the dredged material problem in the New York region is described by Gross (1969, 1974) and EPA (1982); these studies noted that ocean disposal of solid waste from New York, mostly dredged material, was the single largest source of sediment entering the western North Atlantic.

Environmental Impact of Dredged Material Disposal

30. The earliest studies of environmental impact from dredged material disposal (Lunz, 1938, 1942; Wilson, 1950; Ingle, 1952; Ingle et al., 1955) focused on mortality among fish, crustaceans, and oysters exposed in and near disposal operations. In general, these studies concluded that the primary impact of dredged material disposal was physical (see also Chesapeake Biological Laboratory, 1970; Sherk, 1971; Rogers in First, 1972; O'Connor et al., 1977). While organisms covered by disposed sand, silt, or clay were eliminated, the rapid dilution of suspended solids released during disposal operations resulted in very little mortalilty or other effects beyond the immediate impact zone (see, e.g., Pfitzenmyer, 1970; Ritchie, 1970; Macklin, 1961). However, Sherk (1971) noted that suspended sediments could cause effects some distance from the site of disposal if density flows were to form. A "density flow" is a condition in which silt and clay particles can mutually inhibit settling if concentrations exceed 10,000 mg/L. Density flows can move freely under the influence of tide and currents (Masch and Espey, 1967) and may affect organisms up to several kilometers from a disposal site.

31. To our knowledge, Saila et al. (1968) made the first statement

that chemical contaminant effects may be associated with disposal of dredged material. Servizi et al. (1969) reached a similar conclusion after studying the biological impact of contaminated sediments from Bellingham Harbor, Washington. Sherk (1971) suggested that a "satisfactory" investigation of dredged material disposal must include biological, mechanical (physical), and chemical (sorptive) studies of particles.

32. The results of studies on the effects of dredged material disposal from the early work of Lunz (1938) to the present may be summarized as follows: a) disposed dredged material kills most organisms which are buried at a given dump site; b) suspended solids from disposal operations are unlikely to cause significant ecological impact outside the dump site; c) suspended and deposited solids from disposal operations are potential sources for toxicants; and d) toxicants on particles (both in suspension and deposited) may harm marine organisms directly or indirectly.

33. It seems apparent that direct environmental impact from dredged material disposal is likely to be small, especially if disposal is restricted to a single site. If some containment mechanism can be found to mitigate or remove the potential hazard from contaminants sorbed to dredged sediments, ocean disposal of dredged material might be reduced to a problem of minor, if not negligible, magnitude.

Management of Contaminants in Dredged Material

34. Until recently, the bioavailability of contaminants in dredged material was either ignored or was addressed by locating disposal areas further and further from population centers. Little effort was made to reduce the availability of contaminants to the aquatic food chain. Considerations of alternatives to unconfined open-ocean disposal stemmed from the heightened environmental consciousness which came with the promulgation of environmental legislation such as the Marine Protection, Research, and Sanctuaries Act of 1972, as well as the exponentially increasing costs associated with transportation of dredged material to offshore locations.

Present Practices and Alternatives

35. At present, unconfined ocean disposal of dredged material is allowed in designated New York Bight areas, provided that the material has met certain criteria. These include bioassay tests to estimate sediment toxicity and bioaccumulation of selected contaminants (Cd, Hg, PCB, chlorinated pesticides), and evaluation according to a "matrix" predictive of food chain "biomagnification" effects (Engler et al., 1981; Pierce et al., 1981b). These evaluations are also conducted to determine compliance with the London Ocean Dumping Convention which prohibits ocean dumping of Hg, Cd, organohalogens, and petroleum hydrocarbons under certain conditions (Engler, 1980; Pequegnat, 1982). Suggested alternatives to unconfined ocean disposal were considered in a workshop sponsored by the U.S. Army Corps of Engineers (Table 2). Descriptions and practical evaluations of these alternatives appear in Conner et al. (1979). The list of alternatives (Table 2) is extensive, but few data are available on the technical feasibility and environmental success of any of the options. Data are essentially unavailable for some alternatives and they are not considered practicable at this time (e.g., deep ocean disposal, containerized ocean disposal, no dredging, offshore island disposal). The U.S. Army (CE, 1982) specifically addressed environmental impacts associated with current and alternative practices for disposal of dredged material. The Corps concluded, as did the EPA (1982), that continued use of the Mud Dump is preferred to any other disposal alternative, but noted that mitigation of potential impact from contaminated sediments disposed of at the site may be achieved through "special care" (viz., capping) to restrict contaminant bioavailability. Data from the evaluation of present practices at unconfined dumping sites can be compared to data from the evaluation of capped ocean disposal sites to assess the efficacy of capping as an environmentally acceptable method for ocean disposal of dredged material.

Table 2. Alternatives to Present Disposal Practices Currently Under Consideration for the New York District.

MAJOR ALTERNATIVE	ACTIONS (LOCATIONS) UNDER CONSIDERATION
Site Relocation	1. Relocate to Christiaensen Basin 2. Relocate to 106-mile Site 3. Relocate to "Outer Bight" (Northern Area/Southern Area) 4. River/Harbor Disposal (Subaqueous Borrow Pits) 5. Relocate to Long Island Sound
Confined Ocean Dumping	1. Capping for Confinement/Isolation
Upland Disposal	1. Isolate in "Standard" Landfill 2. Construct Containment Facilities (Cofferdams, Diked Containment) 3. Use in Beach Restoration/Beach Nourishment 4. Use as Sanitary Landfill Cover
Miscellaneous	1. Use for the "Creation" of Wetlands 2. Use for Creation of Artificial Reefs (Coastal Zone/Shelf Area)

Dredged Material Capping

36. Capping is considered to be a mitigating measure rather than an alternative to the present practice of dumping at the Mud Dump. It is also a means of complying with the London Ocean Dumping Convention constraints by "rapidly rendering harmless" the unacceptable dredged material through chemical, physical, and biological processes of the ocean (Engler, 1980; Pequegnat, 1982). In simple terms, capping is the burial of "contaminated" material with stable layer(s) of clean dredged material. Clean capping material is material which, at a minimum, meets the present criteria of the bioaccumulation bioassay and passes the "matrix" evaluation. The cap sediment should completely cover the underlying material and prevent its movement; at the same time, the cap should isolate contaminants from the water column and benthic organisms.

37. Capping is not being considered for use on a wide scale since impacts associated with most disposed dredged material have not been demonstrated to be significant enough to warrant modifications to existing methods (CE, 1982; EPA, 1982). Capping is being considered for use in the disposal of: 1) materials which contain substances capable of bioaccumulating or concentrating in exposed organisms; and 2) materials containing toxic substances which would otherwise be prohibited from ocean disposal (Engler, 1980; Pequegnat, 1982).

38. The extent to which contaminants are contained by the capping process is related to: 1) the character of the material dumped; 2) the time lag between deposition of the contaminated material and the capping material; and 3) the permeability of the cap to contaminants.

39. Capping contaminated dredged material with less contaminated material is an extension of the concept of "contaminant inactivation", originally developed for use when dredging was not feasible to remove contaminated sediments. Such situations generally occur in lakes or embayments suffering eutrophication from sewage or industrial discharges. In freshwater lakes, prevention of phosphorus release from the sediments (as well as removal of phosphorus from the water column) may be achieved by application of aluminum sulfate (alum) to the lake water. The floc that forms upon the addition of alum slurries to

phosphorus-laden water precipitates soluble phosphorus compounds and also traps phosphorus-containing particles. This precipitate then forms a seal over enriched sediments, effectively isolating the contaminated sediment from the overlying water. A comparison of the efficacy of this technique with dredging is provided by Peterson (1981). Capping is similar to the physical and chemical inactivation of nutrients in sediments in that: a) placement of a cap over contaminated sediment isolates the contaminated material from the water column; and b) various chemical reactions may take place at or near the interface between capped material and cap that reduce the mobility of the contaminants. The use of clean sediment overlays (capping) rather than a chemical floc to isolate contaminated sediments has been used or evaluated in both the U.S. and Japan. The results of these efforts are included in this summary since the techniques and aims are similar to those for capping of dredged material.

Major Capping Operations

40. Considering the simplicity of capping as a confinement or containment technique, it is surprising that it has been used infrequently. Table 3 summarizes the major capping efforts; the findings are summarized below.

Hiroshima Bay

41. The Japanese government initiated a Marine Environment Improvement Pilot Project (MEIP) designed to develop efficient and economic methods to improve the sea bottoms of inland bays and waterways. Most of the work is directed toward dredging. However, Hiroshima Bay in the Seto Inland Sea was selected for an evaluation of sand overlaying rather than dredging, as a means to reduce nutrient release (Takata, 1981). Sediments in Hiroshima Bay and Osaka Bay are heavily contaminated with sewage sludge which causes severe eutrophication in the water column. Nutrient-laden sediments were removed from Osaka Bay by dredging; in Hiroshima Bay a clean sand cap 0.3 to 0.5 m deep was laid over 6.4 hectares of nutrient-rich sediments (Kuroda and Fujita, 1981). Studies conducted six months after the capping in Hiroshima Bay

Table 3. Summary of Major Capping Operations Reviewed in This Report.

OPERATION	CAPPED MATERIAL	CAPPING MATERIAL	STATUS
Hiroshima Bay	Sludge laden muds 120 cm thick 1300 km^3	1. Clean Sand 2. Oyster Shell	1. Spreading method evaluated 2. Capping in Progress
Stamford-New Haven	Metals-laden harbor mud 37,800 m^3	Cohesive Silt 4 m thick 76,000 m^3	Capping Complete in 1979 Under Study
	Metals-laden harbor mud 26,000 m^3	Sand 3.5 m thick 84,000 m^3	Long Term monitoring in Progress
Norwalk Harbor	Contaminated Fine Sediment 20,000 m^3	Silt/Sand Sediments	Monitoring in Progress
New York Bight	Contaminated Fine Sediment 522,000 m^3	Fine Material 193,000 m^3 Fine Sand 1,172,000 m^3	Present Report

showed reduced rates of nutrient release in the capped areas, whereas nutrient release in Osaka Bay had not been reduced by dredging. Furthermore, a diverse macrobenthos community had replaced the previously polychaete-dominated benthic community in Hiroshima Bay. In summary, the short-term results indicated a resounding success and the pilot project has been continued.

42. Hosokawa and Horie (1981) developed a mathematic model to estimate the improvement in water quality that can be achieved by retarding nutrient release. The model was tested in a simple laboratory study conducted on phosphate release from sediments collected in Osaka Bay. Sediments were contained in glass cylinders and capped with 2-5 cm of clean mud or sand. The results confirmed the model prediction, that capping sediments can effectively reduce release rates and thus improve water quality (Hosokawa and Horie, 1981).

Central Long Island Sound

43. Since 1977, the New England Division of the U.S. Army Corps of Engineers has sponsored the Disposal Area Monitoring System (DAMOS) project. The major objective of the program is to monitor dredged material disposal sites located from Rockland, Maine, to Western Long Island Sound. Under the auspices of DAMOS, two major capping studies have been conducted, one using contaminated dredged material from Stamford, Connecticut, and the other using contaminated dredged material from Norwalk, Connecticut, Harbor. The sites of these capping operations are at the Central Long Island Sound site (Figure 4).

44. The Stamford-New Haven capping operation. The capping of Stamford dredged material with New Haven sediments appears to have been the first dredged material capping program carried out in the U.S. Bulk analysis of Stamford Harbor sediments showed high levels of heavy metals. In order to isolate the contaminated material from the water column and to protect benthic organisms in the disposal area, the Stamford materials were capped with sediments dredged from the "cleaner" New Haven Harbor. Two sites in the Central Long Island Sound Regional Dredge Material Disposal Area were chosen for disposal of the contaminated sediments (Morton, 1980a,b).

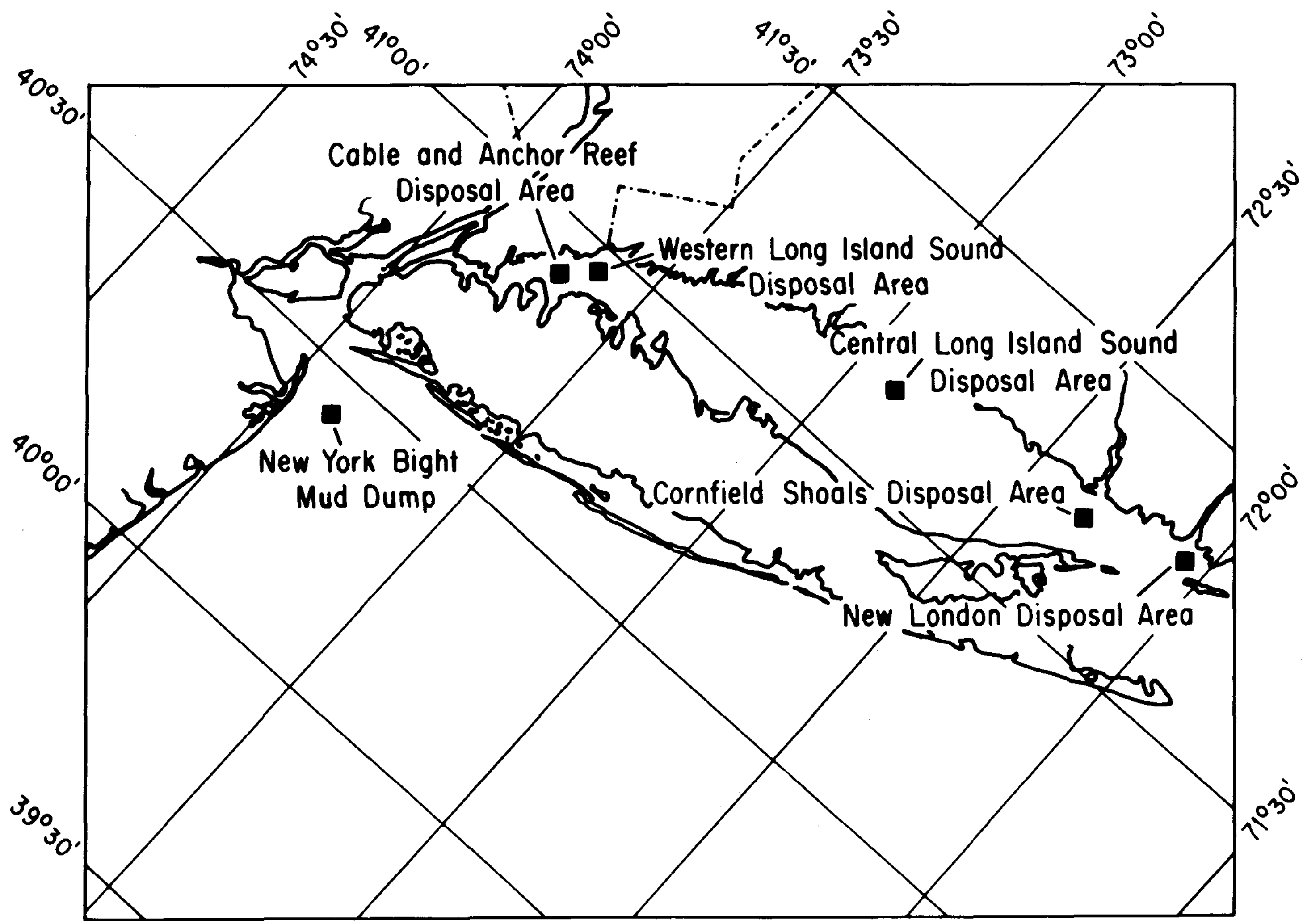


Figure 4. Locations of dredged material dump sites in the region of Long Island Sound, and in the New York Bight

45. One site received approximately 26,000 m^3 of contaminated sediments and was capped with 84,000 m^3 of sand. The other site received about 37,800 m^3 of contaminated material and was capped with 76,000 m^3 of silty, cohesive sediment. The sites were monitored to determine: a) the effectiveness of capping; and b) whether any differences existed between the sand cap and the silt cap.

46. Capping of both sites was completed in June 1979. A survey conducted in August indicated no significant change in the integrity and volume of either cap. However, the silt cap had resulted in a lumpy, rough-textured mound surface, while the sand cap had formed a smooth mound with gently sloped flanks.

47. In November 1979, survey data showed that approximately 10,000 m^3 of dumped material (or 12% of the total cap material) was missing from the center of the mound capped with silt (Morton and Miller, 1980). The sand cap at the other site appeared to be undisturbed. None of the underlying Stamford Harbor deposits were exposed at either site. Investigations to determine the causes of losses at the silt-capped site implicated unusually turbulent conditions in Long Island Sound, caused by a hurricane. Shear stresses generated by the hurricane's waves acting upon the rough surface of the silt cap were apparently sufficient to cause severe erosion.

48. Bulk chemical analysis of dredged material at the disposal sites was included in the capping study to estimate the contaminant load available to biota and the water column. Chemical data presented in DAMOS Annual Reports were limited to copper (Cu), which was presented as representative of the general chemical properties of the dredged material. Concentrations of Cu showed much variability among replicates; in general, the variability was greater among samples having higher Cu concentrations and less among samples having lower concentrations (Morton and Karp, 1981). Morton and Karp (1981) suggest that this localized heterogeneity in metal concentrations might be used to identify dredged material. Presumably, low variability reflects *in situ* sediments in relative equilibrium with themselves, while high variability reflects the incomplete mixing suggestive of contaminated sediments

which have been dredged and deposited at a disposal site.

49. Copper data for the sand-capped site were different from that for the silt-capped site. Pre-capping data for the sand-capped site showed Cu concentrations to be $\approx$ 70 ppm; variability among samples was low. Immediately after sand capping, Cu levels dropped to $\approx$ 4 ppm, but sample variation was higher than the baseline data from "natural" sediments (Morton and Karp, 1981). Successive post-disposal surveys (August 1979 and April 1980) resulted in data which approached the baseline in both concentration and variability. This "return to baseline" was interpreted as a result of deposition of natural sediments on the capping sand (Morton and Karp, 1981). The material under the cap was contaminated with Cu at levels of 400-500 ppm. Further monitoring is being conducted to determine whether the mound surface will maintain baseline concentrations or will show continued increases in Cu concentrations.

50. Fluctuations in Cu concentrations at the silt-capped site were similar to those described for the sand-capped site, except that the silt cap did not reduce Cu concentrations to baseline levels. The Stamford, Connecticut, dredged material deposited at the silt cap site contained approximately 750 ppm of Cu.

51. Bathymetric data and diver observations indicated that some areas of the original deposit of Stamford material at the silt-capped site were incompletely covered. Sediments from these areas showed extreme variability and ranged from 75-450 ppm Cu (Morton and Karp, 1981).

52. Although not originally related to the capping studies, DAMOS included a series of experiments to determine the effect of dredged material disposal on the accumulation of PCBs in the mussel Mytilus edulis (Arimoto and Feng, 1980). Groups of mussels were suspended in the vicinity of the New London disposal site, and samples were collected during and after disposal operations. PCB levels temporarily increased during dumping. However, disposal of dredged material was found not to be a controlling factor for PCB levels in mussel tissues; statistical analyses revealed that river discharge accounted for as much of the

temporal change in PCB levels as could be attributed to disposal operations.

53. At the two capping sites, mussels were suspended near the site and subsequently analyzed for heavy metals content. Data from both capping sites, along with data collected for the uncapped New Haven and the Norwalk disposal sites, were analyzed using 2-way ANOVA. No spatial or temporal variation was detected in data for Cd, Cr, and Ni. Data for Co, Cu, Hg, Zn and V fluctuated in time from April through June 1980 (Morton and Karp, 1981). No explanation for these fluctuations has been provided; presumably they are not related to the caps since no spatial differences were detected. Significant variation by both station and sampling data was detected in the data for Fe concentrations (Morton and Karp, 1981).

54. The Norwalk capping operation. Dredging of Norwalk Harbor resulted in the disposal of approximately 16,000 m^3 of contaminated dredged material and approximately 60,000 m^3 of material which was not considered contaminated. In order to isolate the contaminated material, a capping operation was designed (Morton, 1981). Disposal of the cleaner material was begun in the spring of 1980 and continued through the winter of 1980-81. Between January and April 1981 the contaminated material was dumped to the north of the site designated for uncontaminated sediments. Preliminary surveys conducted in late April indicated an error in the placement of the contaminated sediment. Thus, additional monitoring and redesign of the cap placement was required. Most of the capping material was to be deposited between April and June 1981. Data from post-capping surveys are not yet available; thus, the efficacy of the Norwalk operation cannot yet be evaluated.

Summary

55. Both the MEIP and DAMOS data indicate that capping can be successful in relatively shallow waters having low energy currents and waves. Results from the MEIP program demonstrate that, for nutrients, a relatively thin (0.3 to 0.5 m) sand cap can reduce contaminant release and isolate contaminated materials to the extent that a "normal" benthic

biota may develop. The MEIP program also resulted in the development of successful techniques for application of capping material in shallow waters.

56. The Stamford-New Haven capping project demonstrated the following:

- a. Precision disposal and capping is feasible using taut moored buoys in waters of about 20 m depth.
- b. The sand cap provided greater stability than the silt cap under conditions of very high energy, in this case a hurricane.
- c. Both caps were stable under normal tide and wave conditions.
- d. The silt cap resulted in an irregular surface topography which contributed to erosion under high-energy conditions.
- e. Benthic organisms populated the surface of both caps within a year after disposal; however, the species composition was different and neither cap exhibited a benthic community similar to that of the surrounding sediments (Morton and Karp, 1981). This information should be considered preliminary. Significant recolonization should be expected to take several years.

57. As a result of the data obtained from the Stamford-Norwalk project, the managers of the project have made several recommendations for future capping projects (Semonian, 1981).

- a. Cohesion of the material to be capped should be maintained, if possible.
- b. The surface area of the capped mound should be minimized.
- c. Cap material should present a smooth mound surface; thus, if it is cohesive in nature, clumps should be broken during the dredging operation or the surface smoothed after deposition.

PART IV: THE NEW YORK BIGHT DREDGED MATERIAL CAPPING PROJECT

58. The Port of New York and New Jersey cannot continue to operate without continuous maintenance dredging of 240 miles of Federally authorized navigation channel areas, as well as numerous privately maintained dockage areas, slips, and approach channels. For the period 1970-1978, the annual volume of dredged material removed from the harbor region averaged 8.3 x 10^6 m^3. Some of this dredged material contains significant quantities of bioavailable contaminants. According to Ocean Dumping Criteria (EPA/CE, 1977; Engler, 1980; Pequegnat, 1982), dredged material which causes bioaccumulation of prohibited materials (e.g., metals, pesticides, PCB) must be given special treatment. New criteria for ocean dumping of contaminated dredged material from New York Harbor are being developed according to a "matrix" procedure, in which physical, chemical and biological factors are used to estimate the potential for contaminants in sediments to accumulate in marine organisms (Engler et al., 1981; Pierce et al., 1981a). At present only bioaccumulation data are used to determine the potential environmental impact due to dumping dredged material.

59. During 1979 and 1980 the New York District CE determined that the sediment from several dredging projects in the metropolitan New York area caused contaminant bioaccumulation in test organisms. It was decided, therefore, that the material from these projects should be dumped in the present Mud Dump, and capped with silty material from the Bronx River and Westchester Creek and with sand from the Ambrose Channel. Since the overall efficacy of capping as a mitigating measure had not been proven, the decision to cap was also a decision to carry out studies evaluating the effect of capping at the dredged material dump site. The designated Mud Dump in the New York Bight was divided into quadrants, and each quadrant was evaluated for suitability as an experimental site. Based upon available dumping records (1966-1980), the southeast quadrant was least impacted, and was designated as the Experimental Mud Dump (EMD). The site was not undisturbed, however; the Mud Dump area has been in continual use since 1914 and dredged material has

accumulated in the EMD.

Elements of the Capping Project

60. The New York Bight Capping Study was designed such that the available baseline data from the MESA-New York Bight Study and the limited, but useful, capping data from the New England Division DAMOS project were fully utilized. Many of the principal components of the DAMOS project were integrated into the study of the New York Bight EMD. These included: 1) the Bathymetric Data Acquisition system (BDAS); 2) the Boundary Layer Turbulence system (BOLT); 3) chemical analysis of sediment cores; and 4) a study of contaminant bioaccumulation in the blue mussel (*Mytilus edulis*). Elements incorporated into the EMD study which were not part of DAMOS included a detailed analysis of sediment dry mass losses both at the dredging site and at the dumping site, and pre-dumping chemical analysis of dredged material aimed at constructing a chemical "signature" for dredged material at each project.

61. Pre-project bathymetry for the EMD was obtained in October 1978. These data were used as the baseline for bathymetric surveys carried out after disposal of contaminated dredged material (October 1980) and again after placement of the sand cap (November-December 1980).

62. Contaminated dredged material was removed from various sites in the metropolitan New York area between early March and mid-June 1980. Dumping did not occur sequentially; dumping of dredged material from the New York Port Authority Terminal occurred between 9 March and 7 April 1980 and dredging and dumping of sediment from the U.S. Gypsum facility at Stony Point, N.Y., occurred between 24 March and 15 April 1980. The Port of Newark dredging project lasted from 17 April to 8 May 1980, which overlapped the Seatrain-Weehawken project (23 to 30 April 1980). The two projects used for fine capping material (Bronx River and Westchester Creek) were carried out sequentially, the former between 21 July and 11 August 1980 and the latter from 11 to 23 August 1980. The prime capping material, sand from Ambrose Channel, was cut between 31 October and 10 November 1980. Capping was complete in mid-November, and the first core samples at the EMD were taken on 11

December 1980.

63. Bathymetric surveys and derivation of the sediment budget at the dredging sites and the EMD were carried out by New York District CE personnel. The musssel bioaccumulation study was performed by the New Jersey Marine Sciences Consortium. Research to determine the stability of the sediment cap at the EMD was carried out by the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), and chemical and physical analysis of project sediments and EMD cores was carried out by the New York University Medical Center, Institute of Environmental Medicine.

Summary of Component Project Results

64. Documentation of methods can be obtained from the original reports comprising the Capping Project Study. These are included in microfiche at the end of this report.

Sediment budget

65. The Sediment Budget Study (Tavolaro, 1982) quantified the dry mass of dredged material involved in each stage of clamshell dredging and in disposal activities. The prime objective was to quantify losses of dredged material during dredging, overflow while attaining "effective load", and dispersion after discharge at the EMD.

66. Volumes of sediments were estimated before dredging (in place), in the barges (barge measurements), and after dumping (Mud Dump measurements). Sediment in-place volumes were estimated by before-after bathymetric measurements at each project site. Barge volumes were estimated by displacement, as calculated from measures of barge draft before and after loading. Sediment volumes at the Mud Dump were determined by bathymetry before and after dumping. All sediment volume data were reduced to dry density measurements using a variety of techniques (Bokuniewicz et al., 1978; Suszkowski, 1978; Tavolaro, 1982). Mass balance calculations for the Sediment Budget Study used dry mass, as determined from the volume and density data.

67. Several field studies were carried out to determine dry mass losses associated with dredging alone, barge overflow, and the combined

dredging-overflow operation. Loss of material at the disposal site was not measured directly; rather it was estimated from the difference between the volume of the mound at the EMD and the volumes transported to the EMD for dumping. Correction factors were applied for compaction of the mound with time, based upon empirical data (Bokuniewicz and Gordon, 1980) and numerical modeling techniques (Conner et al., 1979). Mass losses from dredging and the barge overflow operations were estimated from empirical data on suspended solids concentrations obtained at project sites during active dredging.

68. Tavolaro's (1982) Sediment Budget Study estimated a loss of 5.6% of in-place sediment between initiation of a dredging project and disposal at sea (Table 4). The greater proportion of the loss (3.7%, or 66% of the total loss) occurred at the ocean disposal site. The remaining 34% was lost during the process of dredging and barge filling. More material was lost by actual dredging than by intentionally overflowing the barges to achieve "effective load".

Sediment cap stability

69. Analysis of the sediment cap stability (Freeland et al., 1982) encompassed field studies, laboratory studies and analysis, and numerical modeling carried out with data from a variety of sources. Data collection for the cap stability study was restricted to: 1) estimating surficial sediment characteristics at the EMD in November 1980 (immediately after placement of the cap) and in June 1981; 2) a determination of threshold erosional velocities for the sand cap *in situ*; and 3) current measurements in the water column immediately above the sand capping area.

70. Methods for surficial sediment analysis conformed to standardized procedures. Sediment grain sizes were presented as gravel, sand, fine sand,and "mud" (silt and clay) according to phi (ϕ) units. Erosional studies (Young and Gust, 1982) were carried out using SEAFLUME II (Young, 1977; Young and Southard, 1978) which conformed conceptually to the Boundary Layer Turbulence system (BOLT) used in the DAMOS studies of sediment cap stability in Long Island Sound (Morton, 1980b).

71. Since the EMD mound represents a new and unique topographic

Table 4. Summary of dredged material losses from dredging site to dump site for the materials included in the Capping Project.

	In Place Measurements		Barge Measurements		Mud Dump Measurements
Total Volume (cubic yards)	683,554		861,292		510,565
Percent Difference		20.6		40.7	
Percent Difference (In Place vs. Mud Dump)			25.3		
Total Mass (short tons)	359,764		350,116		337,787
Percent Difference		*2.0		*3.7	
Percent Difference (In Place vs. Mud Dump)			*5.6		

Source: Tavolaro (1982).
* indicates loss of organic matter accounted for in the estimate

feature of the Bight Apex which might well affect direction and velocity of currents, a water column current meter study was carried out in conjunction with SEAFLUME experiments. Current meters were deployed at selected sites on and near the EMD during the period November 1980 to July 1981. These data were employed in the cap erosion study, and were also applied in verifying the wave hindcasting study (Drapeau, 1982). Wave hindcasting, a statistical modeling process, was applied to available Bight Apex data to evaluate the impact of the seasonal "wave climate" on sediment cap integrity, and to estimate the likelihood that infrequent events such as hurricanes might breach the cap. The current meter studies (Young, 1982) were carried out using concentration-velocity probes located at three sites on the sand cap, and provided data on suspended solids concentration as well as on current velocities and directions.

72. The effectiveness of the sand capping operation in forming a physically stable layer of sand between the fines and the water column was studied by Freeland and colleagues. Their investigations included not only an evaluation of the cap <u>in situ</u> (presence, thickness, grain size, etc.), but also a series of studies to determine how long the cap is likely to persist under "normal" hydrographic conditions, and what impact major storms might have on the physical integrity of the cap.

73. In the study of surficial EMD sediments, Freeland et al. (1982) determined that an effective sand cap had been laid over the various Project muds as well as the muds from Westchester Creek and the Bronx River. Figures 5 and 6 provide percent sand data on the mound immediately after capping (November, 1980), seven months after capping (June 1981), and the percent change in cap sand at the EMD during seven months at sea.

74. Young and Gust (1982) estimated erosional potential of the sand cap based upon empirical data (SEAFLUME II and CV probes). Threshold shear velocities for the capping material were determined to be from 0.6 to 1.4 cm/sec. Estimated erosional velocities one meter above the bottom were similar just after capping (November 1980; 23 cm/sec) and after seven months (June 1981; 21 cm/sec). Sufficient agreement

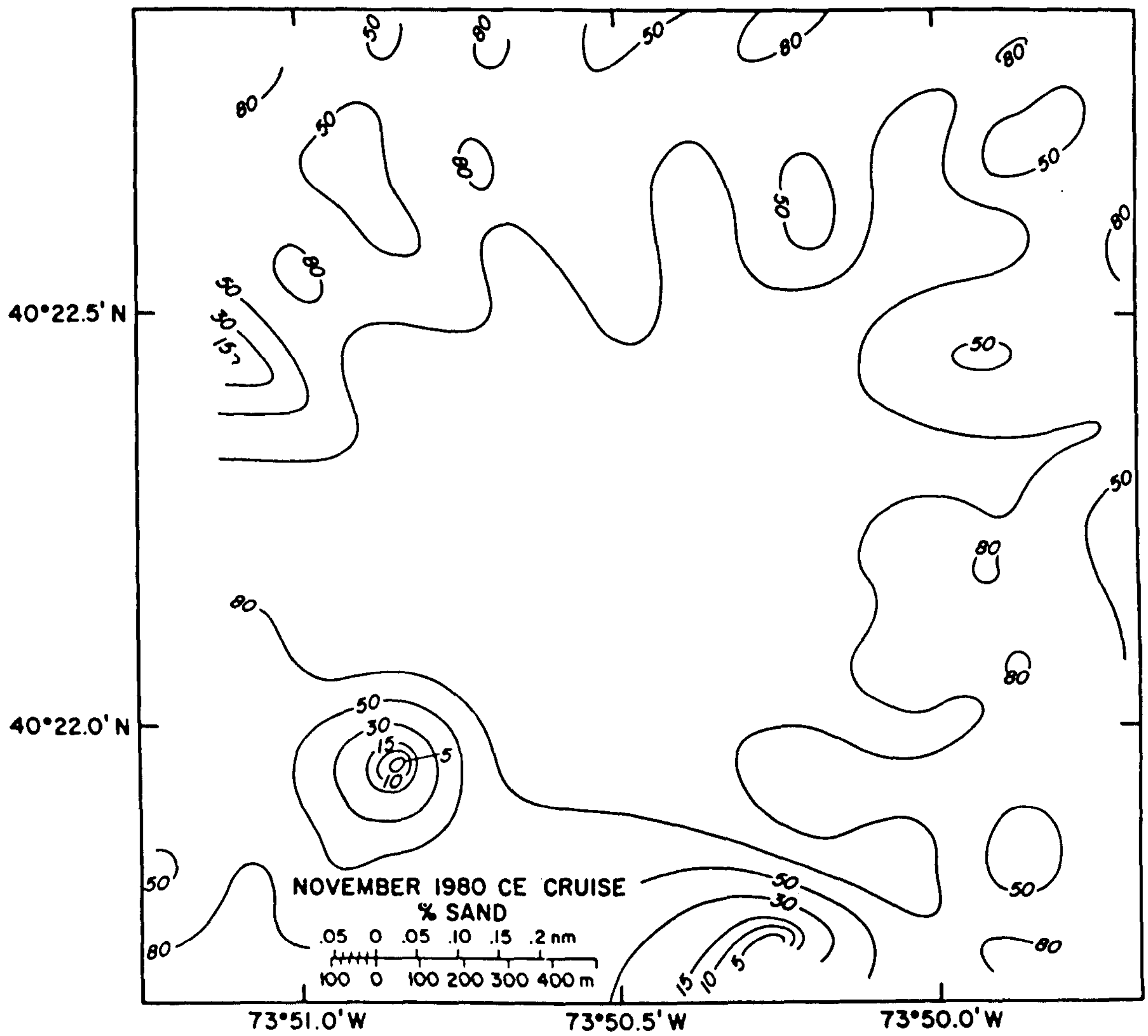


Figure 5. Percent sand in the surficial sediment of the Experimental Mud Dump site in November 1980. Source: Freeland et al. (1982).

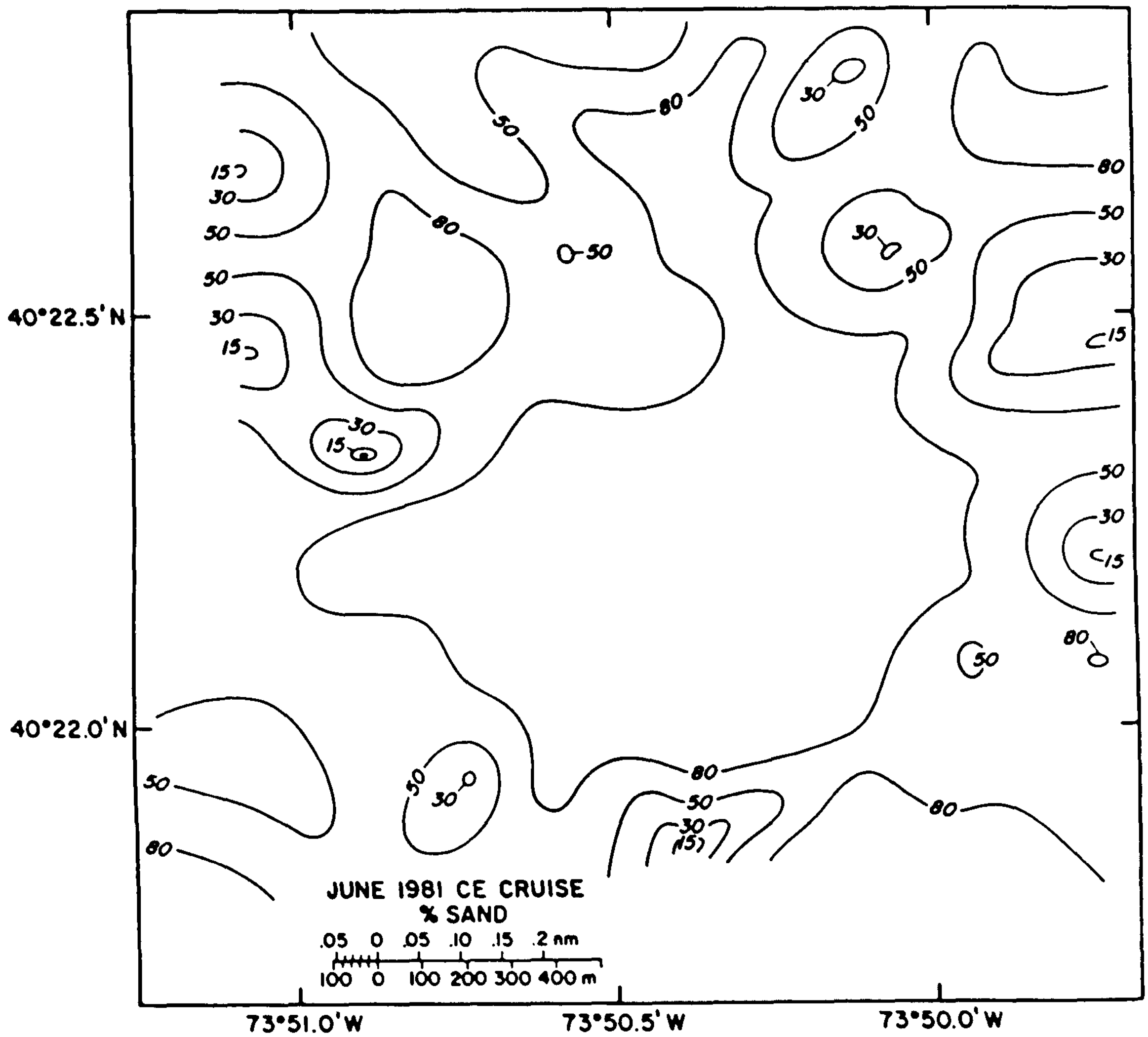


Figure 6. Percent sand in the surficial sediment of the Experimental Mud Dump site in June 1981. Source: Freeland et al. (1982).

was found between observed (SEAFLUME II) and expected values from models that the data were pronounced appropriate for use in estimates of sediment transport at the EMD (Young, 1982; Clarke, 1982), estimates for life of the sand cap, and predictive modeling to estimate the impact of unique meteorological events on the integrity of the sand cap (Drapeau, 1982).

75. Transport of bedload material at the EMD was to the south, and was from 100 to 2500 kg/m/yr, depending upon the calculations used. It is perhaps noteworthy that the cap at the EMD was fine sand, pointed out by Freeland et al. (1982) as the most easily eroded material. The surficial sediment data show an increase in percentage muds on the cap in June, 1981. Freeland et al. (1982) attributed this increase to erosion of fine sand, as well as deposition of fines transported to the site from peripheral locations. Erosion of the sand cap between November, 1980 and June, 1981 was minimal, less than the error associated with estimates of mound volume based upon bathymetry.

76. The erosion simulation model (Clarke, 1982) predicted that the expected net change of the EMD mound would be a loss of ~ 5 cm over a small area of the crest; overall the cap site would show some areas of sediment loss, as well as some areas of sediment accretion. The erosion simulations translate into a minimum of 18 to 46 years for erosional loss of 0.3 m at the EMD.

77. Such predictions are exclusively for "normal" conditions such as those measured by Young and Gust (1982), Young (1982), and Freeland et al. (1982). Further mathematical modeling (Drapeau, 1982) of the probable behavior of the sand cap based upon unusual events such as hurricanes showed that such storms could generate energies more than an order of magnitude greater than the combined wave/current maxima reported by Young (1982). Under such unusual conditions, it is likely that the cap would be breached, and the underlying contaminated muds would be exposed to the sea.

78. Freeland and co-workers stress that the major weakness of the EMD cap is that it is composed primarily of fine sand, the most easily eroded material. In their summary report (Freeland et al., 1982) they

note that, although the cap is likely to maintain its integrity under "normal" conditions,

> "for a margin of safety, it is recommended that additional cap material be placed over the present cap. This should be ... sand, silt and clay consisting of mostly mineral grains, with little or no organic matter, and ... relatively low water content."

Chemical signature study

79. The chemical signature study (NYUMC, 1982) consisted of a multi-component analysis of sediments from dredging projects to determine: 1) whether the project sediments (i.e., contaminated material) could be discerned from cap material; 2) whether the chemical characteristics of individual project subsamples were uniform from barge-load to barge-load; and 3) whether individual projects could be identified by chemical "fingerprint" after disposal at the dump site. New York District CE personnel provided samples of sediments from all projects consisting of aliquots taken from each barge loaded at each project site. Ten-to-fifteen aliquots from each project were subjected to grain-size analysis and processed to estimate dry-weight concentrations of organic content (loss on ignition), Cd, Cu, Pb, Zn, and PCB. Mercury, PAH, pesticides, and radionuclide analyses were performed on composited samples, the makeup of which was determined by a statistical evaluation of homogeneity among project samples. All physical analyses and chemical procedures were standardized according to the CE manual for analysis of sediments (Plumb, 1981) with the following exceptions: 1) some metals analyses were performed by plasma emission (ICAP) spectrometry to determine the comparability of the technique with standard atomic absorption methods; 2) PCB and PAH were analyzed by gas chromatography using glass capillary columns rather than with packed-column; and 3) radionuclide analyses, not included in the CE manual, were performed according to techniques developed by Singh et al. (1979) and Linsalata et al. (1980). Identification and verification of PCB, pesticide, and PAH compounds were exclusively by retention time relative to external and internal standards.

80. Core samples taken at the EMD were all gravity cores.

Depending upon the length of the core, these were either analyzed whole (as above) or according to a progression of depths in the core.

81. The levels of chemical contamination in New York Harbor sediments were greatest for metals, especially zinc; PCB levels were roughly similar throughout all the projects studied. However, unique chemical signatures were determinable only for the Staten Island Project. This was due primarily to very high levels of metals, especially zinc. Some chemical data for all the projects analyzed are given in Table 5.

82. Chemical and physical analyses of core samples showed the presence of a sand cap of varying thickness; X-ray analysis of vibracore samples taken at the Mud Dump site also demonstrated the presence of a sand cap. The depth of the cap was variable and ranged from a few centimeters to more than 1 meter.

83. It was concluded from the chemical signature study that dredged material from the New York Harbor region varies considerably in physical and chemical characteristics. Some regions (e.g., Port Newark and Staten Island) were unique in their high levels of chemical contamination, but no samples from dredging projects were found to contain unique chemicals; discrimination of projects must rely upon the combined levels of "typical" contaminants, especially heavy metals.

84. Levels of organic and inorganic contaminants (e.g., PCB, pesticides, PAH) at the Mud Dump site were equivalent to levels detected in the analysis of samples from individual dredging projects. In gravity core samples taken in December 1980 and August 1981, there was a sand cap containing low levels of contaminants. The cap covered fine-grained, highly contaminated material at some of the dump site sampling locations. Where the sand cap was found to be in place, contaminant levels in the sand, and thus in contact with the water column, were greatly reduced. The presence of a clean sand layer between contaminated fine-grained materials and the water column probably reduced the diffusional transport of most contaminants.

Mussel bioaccumulation study

85. The fourth component of the project was the NJMSC mussel bioaccumulation study (Koepp et al., 1982). The objective of the

Table 5. Mean values for selected chemical contaminants measured for capped dredged material and capping material in the Capping Project Study. Bronx River, Westchester Creek and Ambrose Sand comprised capping material.

	Chemical Contaminants				
	Component (μg/g dry)				
Project	Cd	Cu	Zn	Pb	ΣPCB
Stony Point	2.6	80.3	296.6	119.3	0.92
Weehawken	4.7	237.7	407.0	255.8	0.65
Yonkers	14.1	-	1303.1	558.8	2.03
Passaic River	11.8	692.8	1981.6	1235.6	2.64
Port Newark	14.0	465.1	806.9	439.1	1.59
NYPA	4.4	221.4	332.7	275.9	1.23
Staten Island	11.5	3565.6	10201.2	3168.2	1.94
Westchester Cr.	6.3	427.2	472.7	394.1	1.71
Bronx River	8.1	398.6	519.3	452.8	4.05
Ambrose Sand	0.08	2.5	48.4	6.2	0.10

Source: NYUMC (1982).

bioaccumulation project was to determine if mussels exposed to disposed dredged material accumulated any or all of a pre-established suite of contaminants to levels greater than those accumulated at "control" sites. Eight locations were chosen for mussel emplacement; four were in the vicinity of the EMD, although only one emplacement (Station X) was such that the effects of capping on accumulation may have been evaluated. While some mussels were deployed in the Bight prior to capping, none of the sites were on the EMD. Analyses were performed for Cd, Pb, Hg, PCB, and "No. 2 fuel oil" (petroleum hydrocarbons, PHC) on mussel tissues taken from emplacements throughout the New York Bight.

86. In general, the mussel bioaccumulation study showed bioaccumulation factors (BAF) of one or less relative to the sediments underlying the mussel bags. The body burdens accumulated were quite low, and could be due to bioconcentration from ambient water as much as from the nearby sediments.

87. Most revealing of all the mussel bioconcentration data was the comparison of final body burdens at each station with the initial analyses provided by Koepp et al. (1982). In Table 6, one can see that BAF values relative to the sediments, except for petroleum hydrocarbons (PHC), were uniformly low, 10^{-1} or less for the duration of the exposures. For PHC, the tissue values were essentially uniform although sediment values ranged over an order of magnitude. This suggests that the entire Bight region contains PHC in the water column at levels likely to result in some bioconcentration. It is interesting to note that the PHC data presented by Koepp et al. (1982) in blue mussels from the Cape May control station (50 ng/g) were similar to those reported by MacLeod et al. (1981) and O'Connor et al. (1982) for contaminated stations (~ 120 ng/g). Fuel oil concentrations in mussels from the dump site region were some four orders of magnitude greater, and significantly greater in organisms from the New York Harbor-Lower Bay region. We must consider that the PHC data, as presented (Koepp et al., 1982), may be erroneous.

Table 6. Comparison of contaminant levels in sediments (S) and blue mussels (M) for various stations where mussels were suspended during the bioaccumulation study (Koepp et al., 1982). All values are given as ug/g dry weight.

	Contaminant Levels							
	Hg		Pb		PCB		PHC	
Station	S	M	S	M	S	M	S	M
B	6.9	0.05	180	1.23	-	0.21	8	96
C	2.8	L	88	L	-	L	5	L
D	9.0	0.22	349	1.21	-	0.25	9	123
E	4.4	0.40	129	1.28	-	0.33	59	45
F	11.7	0.18	702	1.36	-	0.23	76	106
X	-	0.04	-	1.0	-	0.15	-	118
Y	-	0.03	-	1.0	-	0.15	-	90

Sources: Sediment data from NYUMC (1982) and Koepp et al.(1982).
Mussel data from Koepp et al.(1982).

Station locations: B= Gravesend Bay; C= Long Beach, NY; D= Christiaensen Basin; E= NW Quadrant, Mud Dump Site; F= 1 mile W of Mud Dump Site; X= Capping Site; Y= Barnegat Light.

Dashed line indicates no data available
L indicates sample lost

Review and Discussion

88. The data gathered during the New York Bight Capping Project are well suited to an evaluation of capping as a method for mitigating the potential effects of dumping contaminated dredged material at sea. In the sections that follow, we have applied these data strictly to an evaluation of capping. It should be pointed out, however, that the content of the Capping Project reports comprises data of significance to the basic oceanography of the New York Bight, as well as to the question of capping.

Sediment losses at the Mud Dump

89. One way in which contaminated sediments at the Mud Dump may affect the environment of the New York Bight is through the transport of particulates and their associated contaminants from the dump site, and their distribution over some as-yet-undefined area. Two Capping Project studies provide data useful in evaluating sediment loss at the Mud Dump. Tavolaro's work (1982) provided estimates of the dry mass of sediment lost due to dumping, while Freeland et al. (1982) evaluated the actual and potential loss of materials at the Mud Dump due to erosion after capping.

90. Tavolaro (1982) estimated that 3.7% of the dry mass of dredged material was lost at the dump site. This estimate was based upon bathymetric determinations (depth-by-difference before and after dumping, using 0.3 meter contour intervals). The calculated loss of dry mass is based upon the assumption that pinpoint dumping at a taut-moored buoy is possible in a system such as the New York Bight. In fact, this assumption is well supported by a variety of studies from the New York Bight, Long Island Sound, and other locations. Science Applications Inc. (1980) showed that dredged material dumped in Long Island Sound could be accurately placed using either permanent buoys as dump site markers, or by using ship-board computers for navigational fixes. Mathematical models predicting the behavior of mud dumps from barges have been evaluated for a variety of sites, including the Duwamish Waterway in Washington, and the New York Bight (Holliday et al., 1978). These models, and the studies of Bokuniewicz et al. (1978), demonstrate that dredged material

from both barge dumps and hopper dredge dumps behaves in a predictable manner during descent and after impact with the bottom at disposal sites. Dredged material placement after dumping at a taut-moored buoy can be accurately predicted. Dry mass estimates of sediment loss, such as those performed by Tavolaro (1982), should provide an estimate of the magnitude of sediment losses during dumping. Recently completed surveys of the New York Bight dredged material disposal site (Dayal et al., 1981) concluded that 85% of all dredged material dumped between 1936 and 1980 remains in the mound. Such data are fully consistent with Tavolaro's (1982) suggestion of very small dredged material losses between March and June, 1980.

91. The causes of sediment losses during dumping and the ultimate fate of lost material were not investigated. We can speculate, however, that some portion of the dumped material was lost during the encounter with the bottom following convective descent to the mud-water interface. Typically, an instantaneous dump of dredged material generates a bottom surge upon impact. This surge carries suspended material away from the impact point in all directions (Brandsma and Divoky, 1976; Holliday et al., 1978), spreading the initial mass over an area dictated by a variety of physical factors. As determined by direct observation in Long Island Sound (Stewart, 1980) and measurements taken in the New York Bight dump site, most particles in the bottom surge settle rapidly in a thin layer around the impact zone. Such areas may have avoided detection in bathymetric surveys, since the sensitivity of the determination was 0.3 m.

92. It is also quite likely that the finer particles in the bottom surge, those with low settling velocities, did not settle and were carried away from the EMD. These particles would become widely circulated within the New York Bight Apex, and represent a real loss associated with the dumping process. At present, no data exist to allow an estimate of the mass lost in this way. The potential loss of contaminants associated with the fines transported away from the dump site is treated below (paragraphs 98 and 99).

93. Part of the study conducted by Freeland and co-workers related

to the loss of sediments from the Mud Dump after placement of the sand cap. Clarke (1982) determined that the expected erosional loss of sediments from the material at the EMD amounted to about 5 cm in a small area at the crest of the mound in the seven months since capping took place. Simulation studies of cap losses, using data from Freeland et al. (1982), and Young and Gust (1982), showed that 28 to 46 years would be required before 0.3 m of the cap would be eroded. Thus, the cap placed at the EMD is highly stable under the hydrologic and meteorologic conditions which prevailed from November 1980 to June 1981. The net change in percent sand in the cap (Figure 6; Freeland et al., 1982) showed that erosion, settling and mixing occurred. Freeland suggested that the small amount of erosion observed in the sand cap could be reduced by placement of another cap; "a mixture of sand, silt and clay consisting of mostly mineral grains with little or no organic matter" (Freeland et al., 1982).

94. By combining data on erosional shear velocities for the cap material (Young and Gust, 1982) and expected maximun currents at the capping site (Wave Hindcasting; Drapeau, 1982), predictions were made as to the integrity of the cap during unique meteorological conditions such as hurricanes. Direct observation of hurricane effects on the Long Island Sound capping sites was possible due to the passage of Hurricane David in 1979. Morton (1980a,b) found that the effects of Hurricane David were different on the two capping sites. The site covered with fines was severely eroded and capped material was exposed; the site capped with sand maintained its integrity. It has been proposed (Morton, 1980a) that the surface features of the two caps were related to cap breaching, or the lack thereof. The cap of fine-grained material was observed to be irregular with lumps of cohesive sediment, whereas the sand cap was smooth. Presumably, the roughness of the cap of fine-grained material led to erosion, while the smoothness of the sand cap resisted erosion due to the lack of small, intense eddy currents forming down-current from irregularities.

95. The cap at the EMD was found to be rather smooth, with some regions identified as mostly sand (Figure 6) and some found to be

primarily muds (Figure 7). During the seven months from November 1980 to June 1981 it was determined with erosion and resettling of particles further smoothed the cap surface. Drapeau's (1982) model, however, predicted that major storms had the potential to generate energies more than an order of magnitude greater than the wave/current maxima reported by Young (1982), and well above the threshold shear velocities for the capping material, as reported by Young and Gust (1982).

96. The cap at the EMD, therefore, must be viewed as possessing the potential to be breached during major storms. Fortunately, such events are not frequent. The combination of a smooth, thick cap (> 1 m; NYUMC, 1982) at the EMD, comprised of materials rather resistant to resuspension and erosion (Clarke, 1982), guarantees the integrity of the EMD cap for a long time to come, under normal conditions of wind and tide. The addition of more material to the sand cap would increase its integrity, especially if any covering added to the cap consists of material less easily eroded than the fine sand already in place (Freeland et al., 1982).

Chemical losses at the dump site

97. A variety of organic and inorganic chemical contaminants are associated with dredged material (Mueller et al., 1976; 1982; O'Connor et al., 1982). Since many of these contaminants are sorbed to particulates, any loss of dredged material during ocean dumping may be inferred to be a loss of contaminants as well. The Capping Project allows a direct but crude estimate of chemical losses to the environment as a consequence of ocean disposal. We combined the dry mass loss estimates of Tavolaro (1982) with bulk chemical analyses (NYUMC, 1982) and determined how much of each contaminant might have been "lost", and possibly made available to marine populations during dumping.

98. In order to make such estimates of contaminant losses, two assumptions were made. First, we assumed that the dry mass estimates of loss associated with disposal were reasonably accurate. Second, we assumed that the contaminant levels of any sediment lost in the disposal process were similar to the levels of contaminant measured in bulk analysis from barge samples (NYUMC, 1982). Using bulk sediment data for

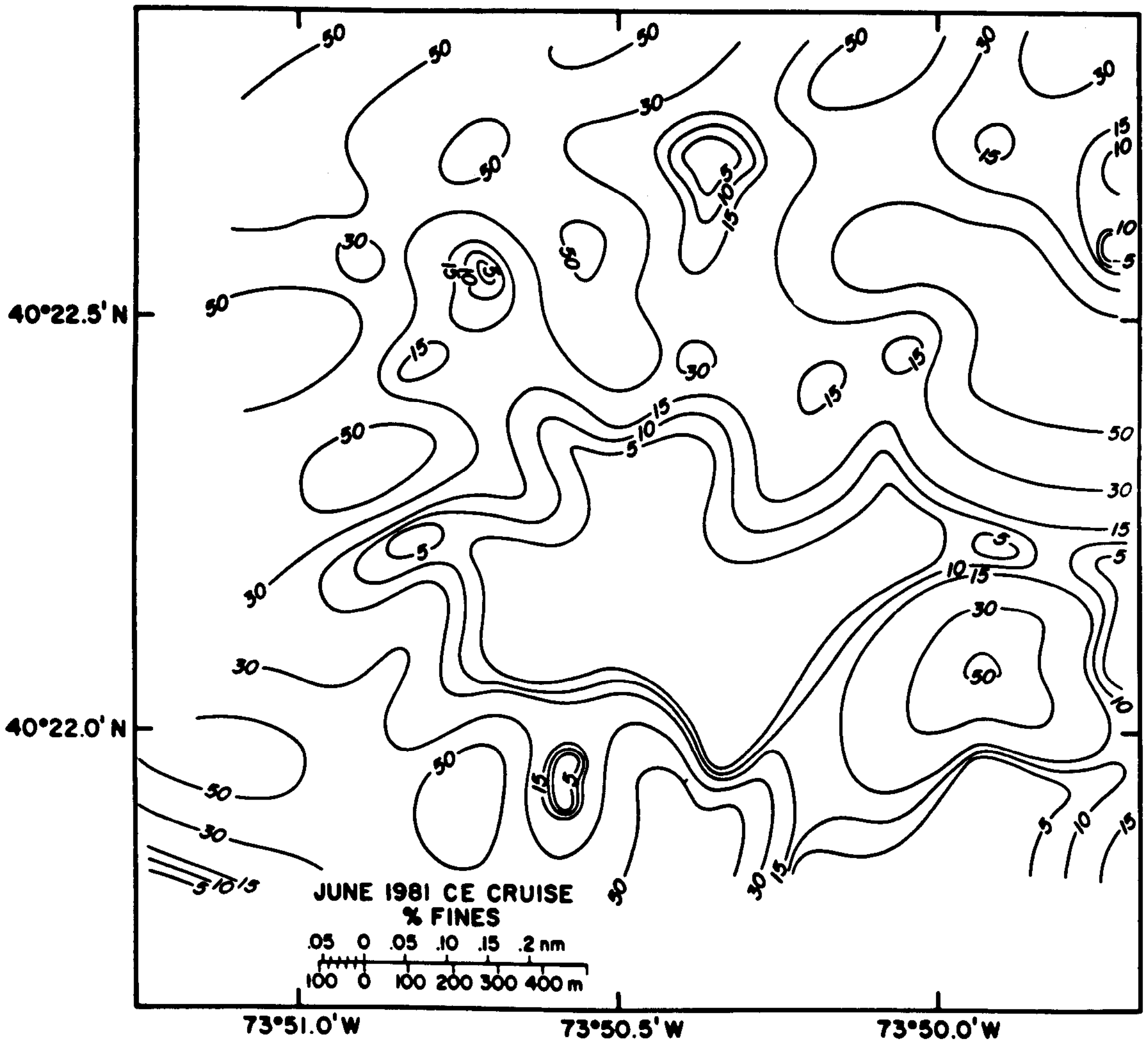


Figure 7. Percent fine sediments (muds) in the surficial sediments of the Experimental Mud Dump site in June 1981. Source: Freeland et al. (1982).

calculating contaminant losses is probably not a serious underestimate, since the majority of the material dredged and disposed in the Capping Project was silts and clays (NYUMC, 1982). Correcting for total volume on a project-by-project basis, and using the mean sand content of each project, we estimated that 16% of the material disposed of at the EMD was sand. Thus, estimates of contaminant loss should be underestimated by no more than 16%. Contaminant losses were calculated based upon Tavolaro's (1982) estimate of dry mass lost during ocean dumping and the NYUMC (1982) mean contaminant concentration by project. Calculated losses are given in Table 7.

99. There exist no data with which one might predict the proportion of particulate-bound contaminants which settle immediately adjacent to the mound, and those which disperse beyond the designated dump site. In previous studies of the bottom surge from instantaneous dumps in the New York Bight, the high levels of suspended solids initially encountered 800 feet from the dump decline to background levels in about 17 minutes, suggesting rapid redeposition of particles in the bottom surge. We can only speculate that the major fraction of lost particles settled to the bottom within the designated dump site.

100. A second mechanism for contaminant loss may be dissolution or desorption of the contaminants both prior to and after the cap has been put in place. Release of contaminants may occur prior to capping due to dissolution and desorption of contaminants from sediments, or due to extrusion of interstitial water as the dredged material mound compacts under its own weight (Bohuniewicz and Gordon, 1980; Tavolaro, 1982). Some contaminants must be released during dumping based simply upon the chemistry of various contaminants in seawater. For example, Segar and Cantillo (1976) have observed increased levels of Cd in Bight waters associated with dredged material dumps. Dayal et al. (1981) have shown that some release of sediment-associated metals may be expected at the dump site due primarily to cation exchange, dissolution, and extrusion of pore waters. Their estimates are not directly applicable, however, since they were not based upon analyses of capped sediments.

Table 7. Estimated dumping losses of major contaminants at the EMD. Percent of total losses, by project, is in parentheses. Losses of contaminants are calculated based upon dry mass losses of 3.7%.

PROJECT	CALCULATED MASS LOST AT EMD ($kg \times 10^6$)	CONTAMINANT LOSS (kg) Cd	Cu	Pb	Zn	PCB
Stony Point	3.19	8.3 (10.1)	260 (2.1)	380 (3.3)	940 (2.8)	2.9 (18.6)
Weekhawken	1.31	6.2 (7.5)	312 (2.5)	340 (2.9)	530 (1.6)	0.9 (5.4)
Passaic River	0.07	0.8 (1.0)	49 (0.4)	87 (0.8)	140 (0.4)	0.2 (1.2)
Port Newark	1.40	20.0 (23.8)	650 (5.3)	620 (5.4)	1100 (3.4)	2.2 (14.1)
Staten Island	2.90	33.0 (40.5)	10300 (83.9)	9200 (80.0)	30000 (88.6)	5.6 (35.7)
N.Y. Port Authority	3.20	14.0 (17.1)	700 (5.7)	880 (7.7)	1100 (3.2)	3.9 (24.9)

Based upon data from Tavolaro (1982) and NYUMC (1982).

Organic contaminants

101. The release of PCB, pesticides, and petroleum hydrocarbons during the dumping of dredged material and from the dredged material mound is a matter for conjecture. Most organic contaminants are less soluble in seawater than in estuarine water, which argues against dissolution; however, intense cation exchange activity on settling particles could temporarily displace organics to solution. It is our opinion that the tendency for sediments to strongly bind most organics would override the tendency toward their desorption and solution (Hiraizumi et al., 1979; Rossi and Thomas, 1981). The available data on dissolved PCB or PAH in seawater or estuarine water from the New York region are sparse. Estimates range from 0.01 to 0.1 μg/L (0.01 to 0.1 x 10^{-9} g/g seawater). Considering that average concentrations of PCB and PAH in sediments range from about 1.0 to 10 x 10^{-6} g/g, it can be seen that the tendency for dissolution is small (10^{-3} to 10^{-4}), and that organics will preferentially remain associated with finely divided solids.

102. There exist very few direct studies of the movement of organic contaminants from deposited sediments to the water column. Ditoro et al. (in press) working with Saginaw Bay sediments showed that vertical diffusion rates for PCB were < 1 cm/year. We know of no similar studies for petroleum hydrocarbons or PAH in deposited sediments. Based upon knowledge of sorptive characteristics of organic contaminants, however, it is possible to estimate the relative potential for vertical diffusion and release of organic contaminants from dredged material. The vertical diffusion constant should be related to: a) the partition coefficient of the compound; b) the particle size distribution of the sediment in question; and c) the organic content of the sediment (Ditoro et al., in press). Quantities of a contaminant released from a sediment will be primarily related to: a) the diffusion rate constant; b) the depth of sediment through which a contaminant must diffuse; and c) the concentration gradient of a contaminant at the mud-water interface. These factors are poorly understood at present, and not quantifiable for organics. Most authorities agree that, in the absence of data, it is reasonable to assume that the release of organics from deposited

sediments can be reduced by covering the contaminated sediments with clean sediments. Covering (i.e., capping) has the effect of: a) increasing the diffusional distance (and time) between contaminated material and the water column; b) decreasing, by dilution, the relative concentration of the contaminant as it approaches the mud-water interface; and c) increasing the probability that sediments will bind organics by providing an excess of sorptive surfaces. Bioaccumulation studies (discussed below; paragraphs 109-113) confirm these expectations.

Inorganic contaminants

103. The release of metals from deposited sediments has been studied in much greater detail than the release of organic contaminants. In undisturbed sediments, the release of sequestered metals requires several steps. The metals must first be released to the sediment interstitial (pore) water. Then the metal must diffuse to the sediment-water interface (often involving multiple sorption-desorption steps), and ultimately must pass through the interface and enter the water column. Many factors, including Eh, pH, bacterial activity, and the presence of various nonmetallic species (sulfides, chlorides, carbonates), combine to control this process (Lu and Chen, 1977; Neff et al., 1978; Forstner and Wittmann, 1979).

104. The release of metallic contaminants from dredged material is controlled by the same processes, but with the addition of substantial mixing, partial aeration, and dilution during dredging, disposal, and consolidation of the dredged material pile. The release of metallic contaminants from dredged material at New York's disposal areas has been estimated by Dayal et al. (1981), and by the DAMOS program in Long Island Sound (Morton and Karp, 1981). Brannon et al. (1980) have published the results of laboratory studies to determine the strength of binding and release potential for a variety of metals in waste dredged material.

105. The results of such field and laboratory studies demonstrate that, while actual release of metals from waste dredged material varies according to the physical characteristics of the dredged material, the potential for release of metals from disposed New York Harbor sediments

can be given. Brannon et al. (1980), using sediments from several sources, showed that Zn had the greatest release potential; Hg, Pb, Cd and As showed very little mass release to the water column. Field studies (Arimoto and Feng, 1980) and microcosm studies (Rubinstein et al., in press) confirm these predictions. Studies of Cu concentrations at capped sites in Long Island showed little migrating through capping material to the water column (Arimoto and Feng, 1980). New York Harbor sediments subjected to elutriate tests released very little Cd or Hg to the water (Rubinstein et al., in press).

106. Dayal et al. (1981) estimated that from 42 to 67% of the metals (Fe, Mn, Cu, Pb, Hg, Cd) associated with disposed dredged material was likely to remain in the deposit for long periods of time. Their estimate, based upon data from an uncapped portion of the New York Bight disposal site, includes losses due to several factors: particulate dispersion, pore water extrusion, bioturbation, and erosion. Based upon pore water analyses, they concluded in agreement with Brannon et al. (1980) that Cd, Cu, and Hg were likely to show little diffusive loss. Iron and Zn were assessed by Dayal et al. (1981) as having the greatest release potential at the uncapped Mud Dump.

107. As with organic contaminants, the overall effect on metals of capping waste dredged material would be: a) to increase the distance over which diffusion must occur if metals are to be released to the water column; and b) to decrease release to the water column by dilution and reduction of the metals concentration gradient at the sediment-water interface. Unlike the situation with organics, however, our understanding of metals geochemistry suggests an additional barrier to metals diffusion in a sand cap. This consists of an increased zone of oxygenation near the sediment-water interface which decreases the flux of chemical constituents into the overlying water. The combined effects of longer diffusional distance, and reduced concentration gradients with an oxygenated layer decreasing metals flux rates, strongly suggests that capping contaminated sediment with clean sand should reduce significantly the loss of metals to the water column.

108. The Chemical Signature Study (NYUMC, 1982) and the work of

Freeland et al. (1982) at the EMD may be applied to estimates of chemical loss, and the extent to which capping at the New York Bight EMD was a success. Freeland et al. (1982) showed a sand cap firmly in place over much of the dredged material mound. The cap, according to NYUMC (1982), had an average depth of 1 m or more, and the concentrations of contaminants in sand layers were significantly lower than in the underlying fine material. It is our conclusion that the sand cap has successfully isolated contaminated materials from the water column and, if not breached, should provide a barrier effective in reducing contaminant losses over long periods of time.

Bioaccumulation

109. There are several reports documenting bioaccumulation of contaminants at or near the New York Bight ocean disposal sites. Most of the available data have not come from the dredged material dump site and most of the analyses have focused on PCB and metals. O'Connor et al. (1982) have summarized the data from MacLeod et al. (1981) concerning PCB and PAH in biota from the Bight region. O'Brien and Gere (1979) and Pequegnat et al. (1980) studied bioaccumulation of PCB and PCB/metals, respectively, at the dredged material dump site and at a variety of "control" locations. As part of the Capping Project, Koepp et al. (1982) studied the accumulation of metals, PCB and petroleum hydrocarbons ("No. 2 fuel oil") at the EMD and several control sites.

110. Some caution must be observed when interpreting or applying the Capping Project bioaccumulation data (Koepp et al., 1982). First, as noted by the authors, before-after evaluation of contaminant accumulation by mussels cannot be made; mussels were not emplaced at the EMD prior to laying on the sand cap. Furthermore, mussels were in place at the EMD only from January to July 1981, whereas comparison sites were occupied from August 1980 through July 1981. Koepp et al. (1982) acknowledge that temperature differences may have affected the bioaccumulative response.

111. In general, the mussel study showed bioaccumulation factors (BAF) of one or less relative to the sediments underlying the mussel bags. The body burdens that accumulated were quite low overall and

there is an equal chance that the source was the ambient water rather than the nearby sediments.

112. Other bioaccumulation studies carried out on or near capped dredged material have shown essentially no increase in the accumulation of metals or of PCB compared to control stations (Morton and Karp, 1981). Such results are of little positive value in evaluating the efficacy of the capping effort as a means of isolating contaminants from either the water column or marine biota. Indeed, the vast majority of research carried out to determine whether marine organisms accumulate contaminants from sediments has so far yielded negative findings; namely, sediments, whether capped or uncapped, in-place or recently disposed, rarely cause elevated contaminant levels in natural or implanted biota (Gambrell et al., 1978; Pequegnat et al., 1978; Neff et al., 1978; Morton and Karp, 1981; Windom, 1973; Burks and Engler, 1978; Hirsch et al., 1978; O'Brien and Gere, 1979; Wright, 1978; Pierce et al., 1981a; Rubinstein et al., in press). The chemical basis for such results is rapidly becoming understood (Hiraizumi et al., 1979; Nau-Ritter, 1980; Klinkhammer and Bender, 1981; Hazen and Kneip, 1980; Dayal et al., 1981; Rossi and Thomas, 1981; Wright, 1978; NYUMC, 1982). Simply stated, the contaminants that are sorbed or otherwise particle associated, or which exist in precipitated and insoluble forms, tend not to dissolve or otherwise dissociate from sedimentary deposits. Even under conditions where contaminant-laden particles may form a portion of the diet, as for *Nereis*, bioaccumulation of metals and chlorinated organics is low (Rubinstein et al., in press).

113. The reviewed data of O'Connor et al. (1982) and O'Connor and Rachlin (1982), and the experimental data of O'Brien and Gere (1979) and Pequegnat et al. (1980) show that significant bioaccumulation is unlikely to occur, even at uncapped deposits of dredged material in the New York Bight region (see also Raltech, 1981). For studies in which reference stations were used, crustaceans, fish, mussels, and clams showed no greater contaminant accumulations at the dump site than at other stations in the Bight region. In fact, bioaccumulation rates within the New York Harbor proper (Gravesend Bay) were generally greater than at the

Mud Dump site. The laboratory data of Rubinstein et al. (in press) showed that the low rates of contaminant accumulation directly from sediments are due to the reduced bioavailabilities of metals and organics in finely divided, organic-rich harbor muds.

114. Any reduction of contaminant levels in the water column or the diet of marine organisms will lead to reduced rates of bioaccumulation of contaminants, as well as increased rates of elimination of existing body burdens (O'Connor and Rachlin, 1982; Pizza and O'Connor, in press). The presence of a cap at the EMD, by reducing contaminant levels in the water column and in the marine food chains of the New York Bight, will eliminate any increase in ecosystem degradation which might occur due to bioaccumulation of toxicants from contaminated dredged material.

PART V: CONCLUSIONS

115. The New York Bight Capping Project demonstrated that through precision dumping, contaminated dredged material may be covered with a cap of clean material. The cap material, consisting primarily of fine sand, resisted erosion for 16 months, at which time the cap averaged more than 1 meter in thickness. Natural sedimentation and mechanical reworking of the cap have resulted in a mound having a smooth contour with surficial sediments composed of fine sands and muds. Other studies have shown that these characteristics render dredged material deposits resistant to erosion.

116. The presence of a cap at the EMD is expected to reduce the movement of metals and organic toxicants from contaminated sediments to the water column. Other studies have shown that the release of nutrients and toxicants from contaminated sediments decreases after capping. In Japan, sand caps of 0.3 m depth have reduced losses of nutrients and metals from sediments; in Long Island Sound, caps on contaminated sediments reduced the movement of Cu, PCB, and other toxicants into the water column.

117. The sand cap at the New York Bight EMD should remain in place for as long as 20 years, under normal conditions of weather, tide, and current. Estimates of erosional rate show that it may take between 18 and 46 years for erosion to remove the top 0.3 m of the cap. Unique events or major storms will cause erosion and possible breaching of the cap.

118. Bioaccumulation studies were inconclusive as to the ability of capping to prevent or reduce contaminant uptake by blue mussels. However, the low bioaccumulation rates observed in the mussel study, and the results from other capping studies, allow the conclusion that contaminant uptake due to loss of metals or organics from the capped material is unlikely to occur.

119. Given the conditions prevailing in the New York Bight, capping can be an effective and efficient procedure for dealing with contaminated dredged material. The success of the Capping Project raises the possibility of integrating the management of contaminated dredged

material disposal with routine disposal operations. Since project-by-project capping could be impractical as a management scheme, we suggest that contaminated dredged material could be disposed of at any time, at designated sites, provided that clean materials are available for covering the contaminated material. Such procedures would constitute repeated, successive capping events. Such a management scheme would result in multiple layers of contaminated sediment at the dump site, covered to the maximum possible depth by layers of clean, fine-grained, and sandy materials.

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